# Tappi

PUBLISHED BY THE TECHNICAL ASSOCIATION OF THE PULP AND PAPER INDUSTRY

SEPTEMBER 1950

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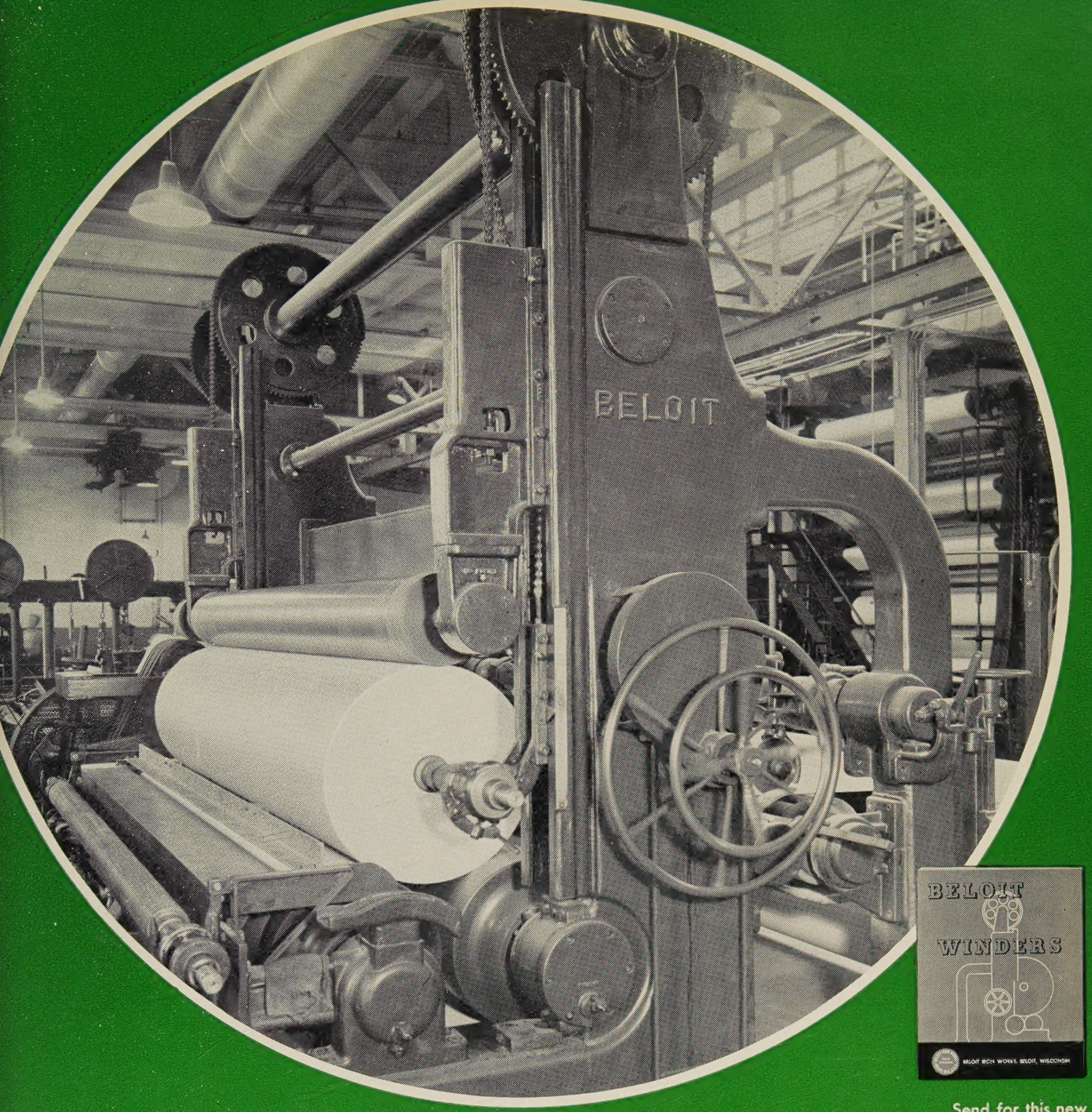





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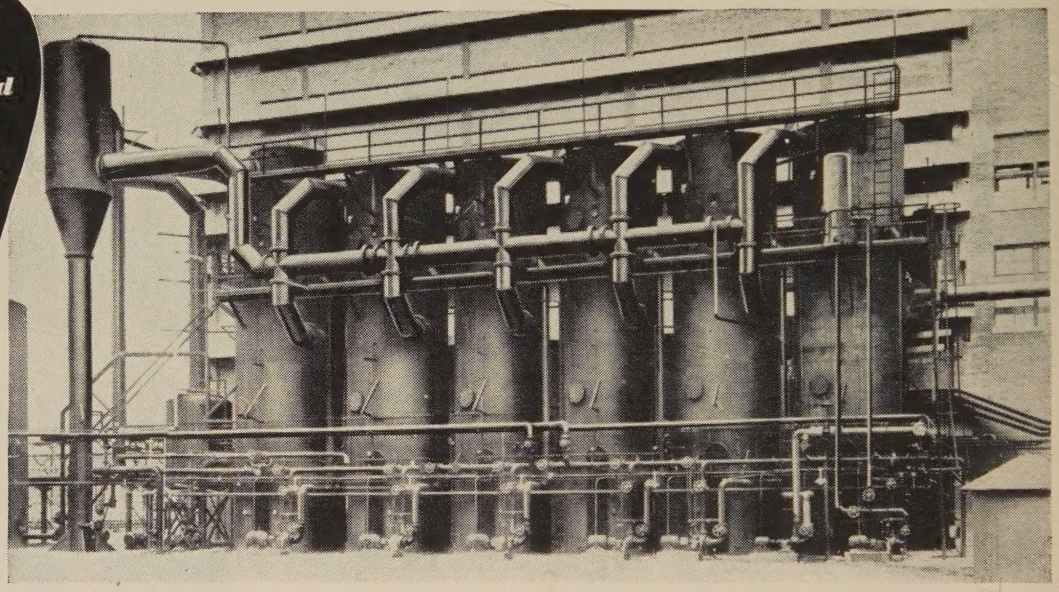

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SEPTEMBER 1950

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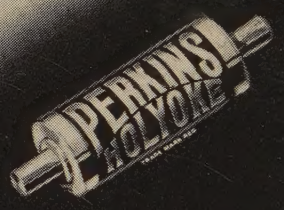


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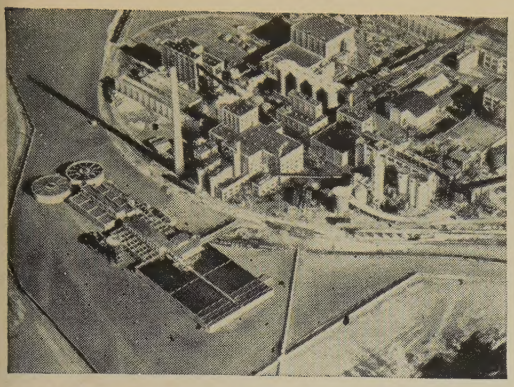

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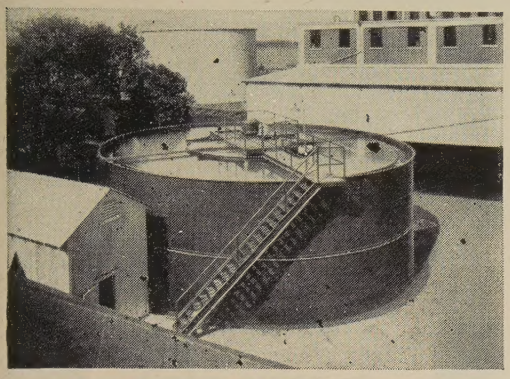

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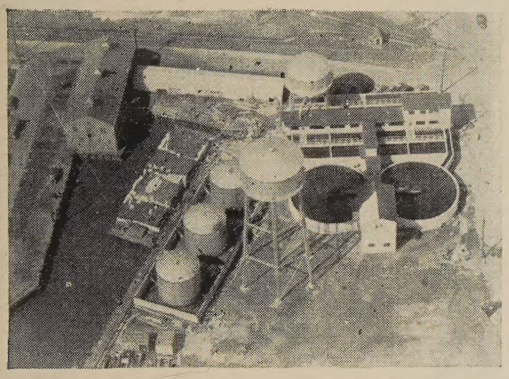

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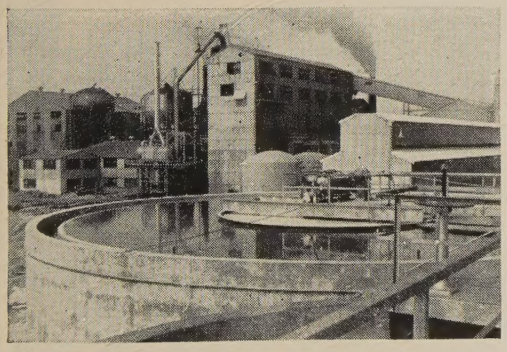

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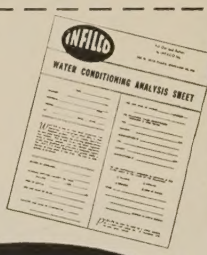


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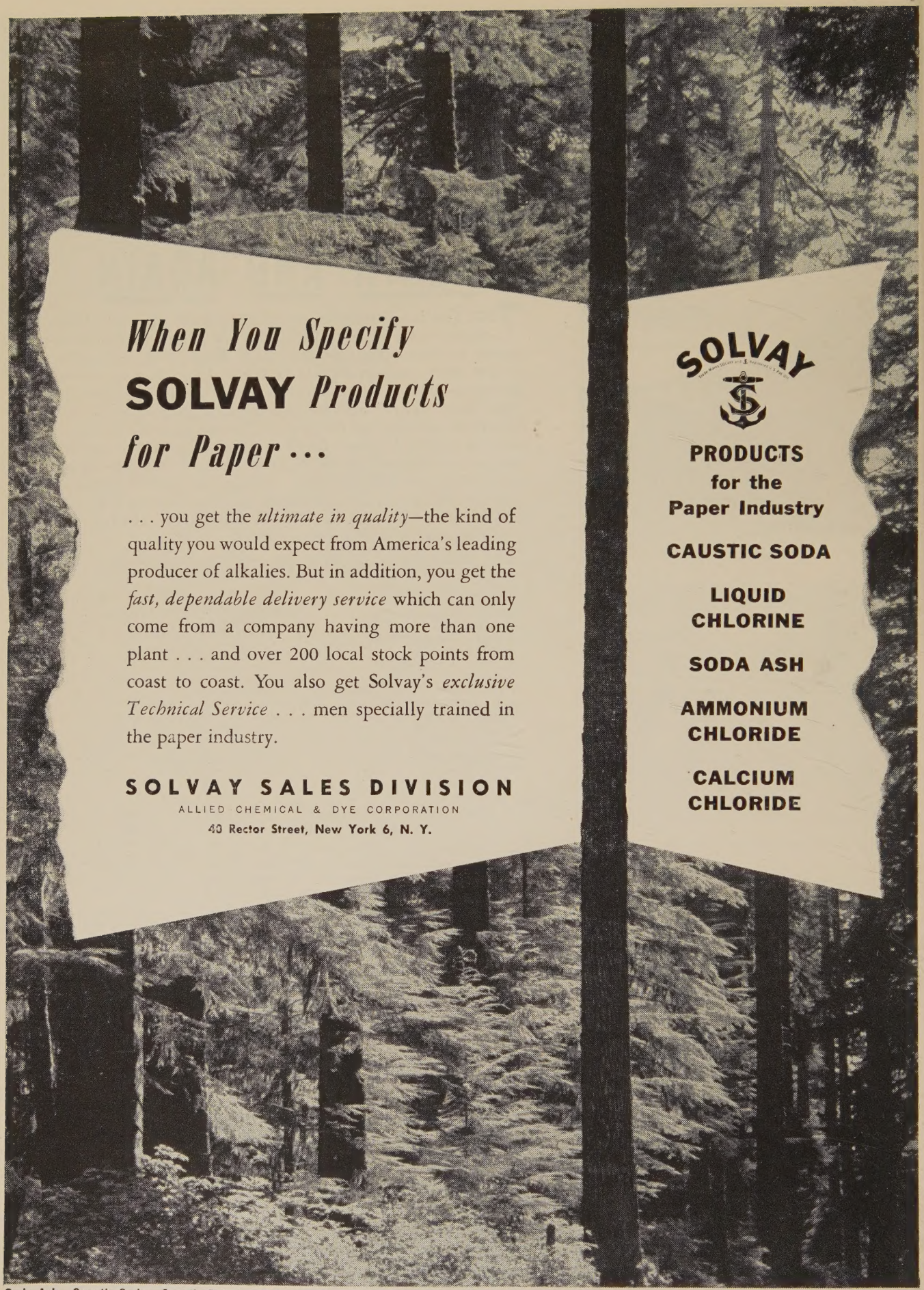
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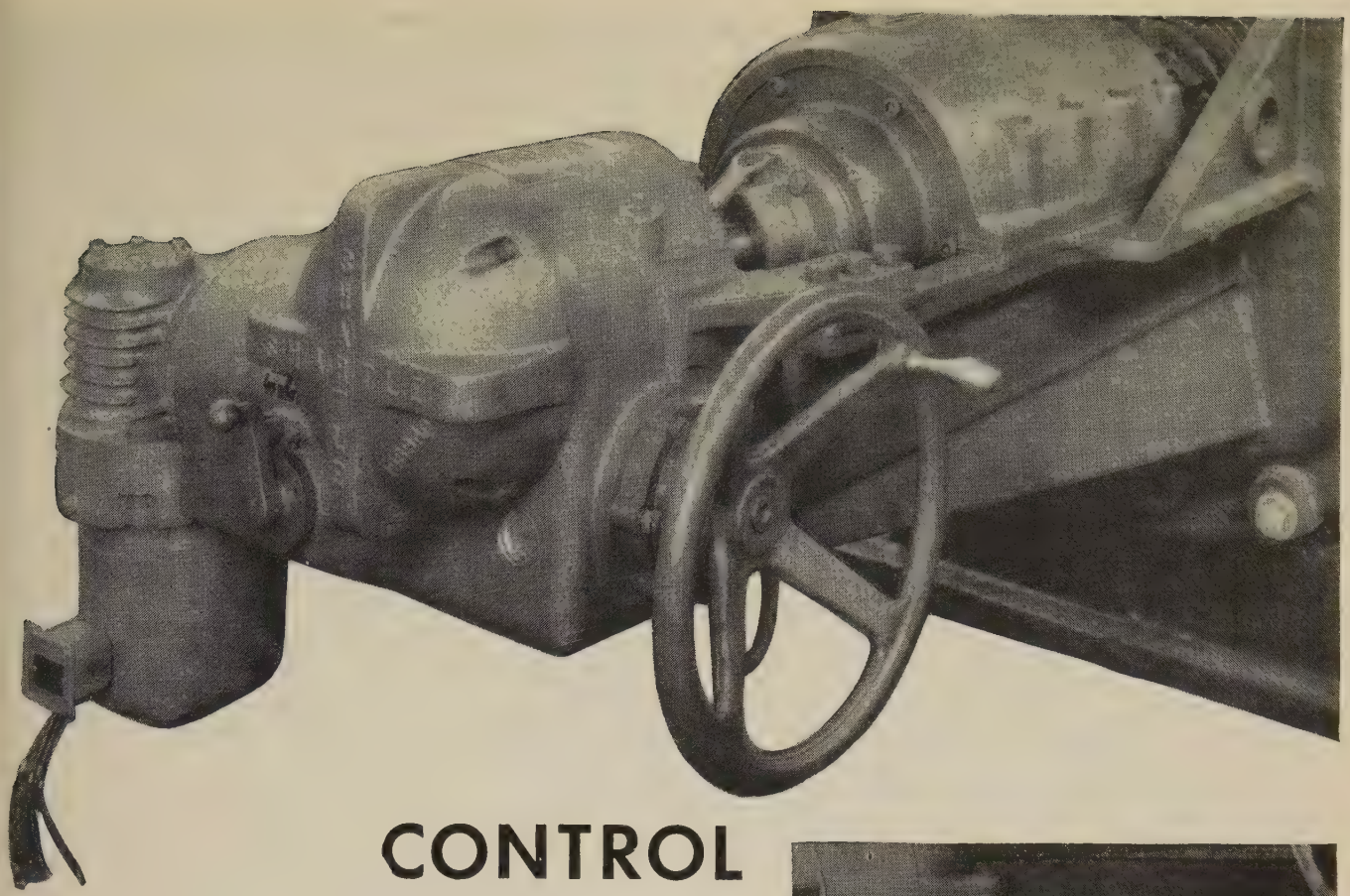

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Remote control marches on—this time through the installation of Duotrol on Jordans and HYDRAFINERS to keep plug settings "right on the beam."

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*Power-time factor*—Correct fibre treatment by Jordans and HYDRAFINERS determined by automatic control of power and time factors.

**DUOTROL—the mechanism**

A worm gear box connected to the plug adjustment screw for plug manipulation either by hand wheel, or electrically and automatically from a remote-control panel board.

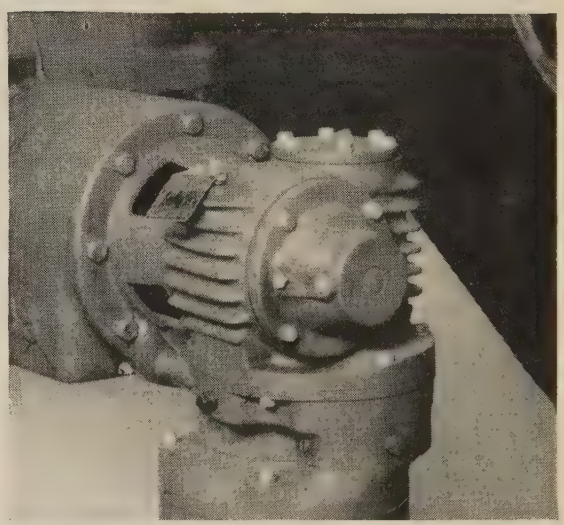
Indicating and recording meters chart required power which, through relays, set up or back off HYDRAFINER and Jordan plugs to compensate for changes in consistency, freeness, capacity, etc.

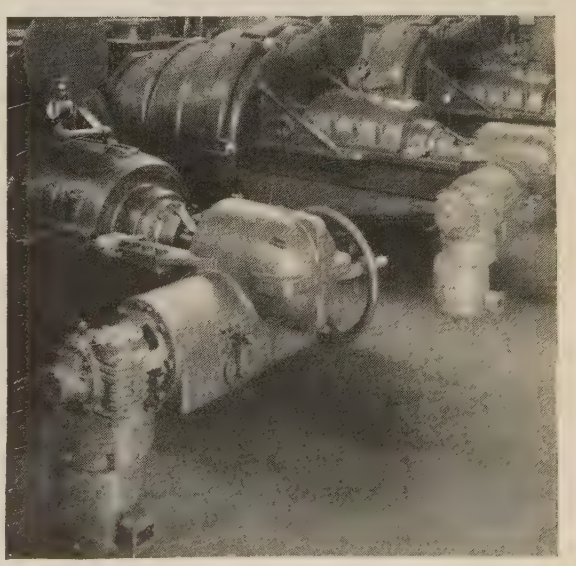
**DUOTROL—the benefits**

Duotrol plug control vs manual plug settings show a time cycle reduction of around 20%. Duotrol vs manually controlled treatment of the stock tested approximately 10 points higher in the finished sheet. Actual mill report.

Duotrol is applicable to all jordans of all makes, to HYDRAFINERS and to all Conical refiners.

Already scores of Duotrols are in service helping to produce more uniformly treated stock as well as to reduce horse power and save labor. *For full particulars write—*





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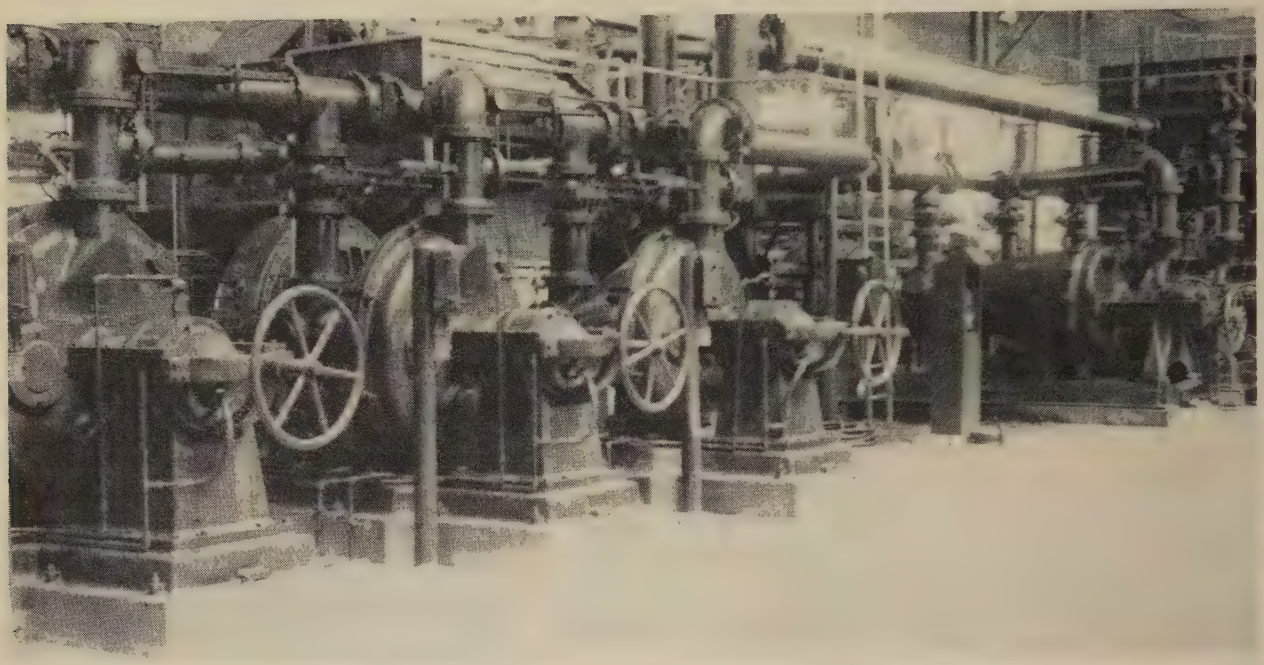

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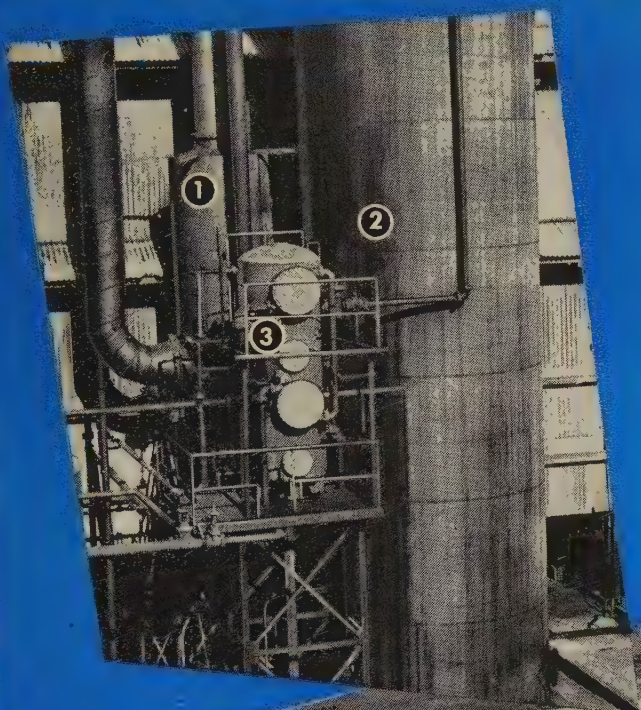
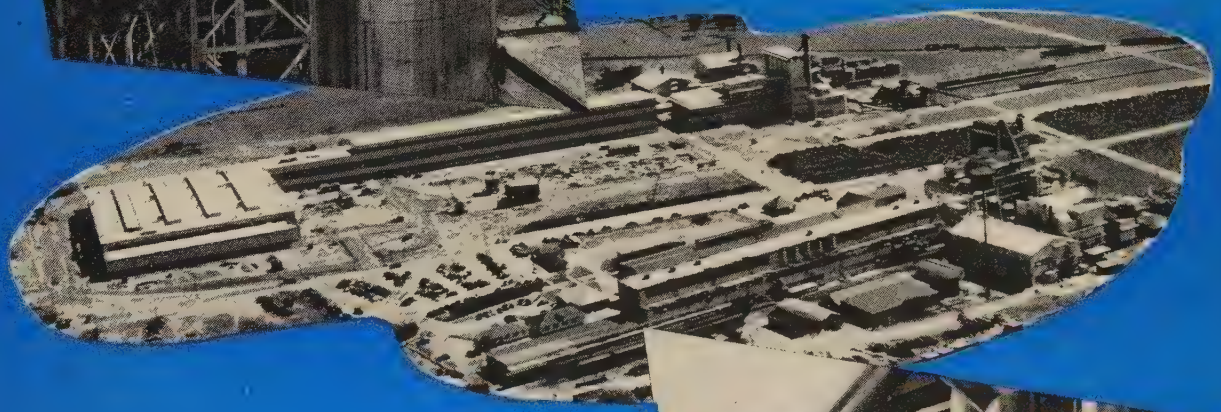



At the St. Regis Paper Mills in Pensacola, Florida, two types of blowdown recovery systems are in operation. In the Vapor-to-Liquid System *(left)* steam is condensed in the atmospheric condenser (1) and hot condensate is stored in the accumulator tank (2). This condensate, contaminated by some black liquor and pulp, is flashed under vacuum and the resultant clean vapors heat mill water in the tubes of the flash heater (3).

In the Surface Condenser *(below)* mill water flowing through the tubes is heated by steam condensing in the shell. The expansion chamber at vapor inlet prevents pulp from reaching tube bundles.



Properly engineered recovery equipment not only **costs you less** in the long run but ***increased operating efficiency*** and ***large fuel savings*** may also be enjoyed from the outset.

If you are contemplating improvements at your mill, our specialists on pulp and paper mill equipment will be glad to help you with your engineering problems.

Foster Wheeler Blowdown Recovery Systems are discussed in the May, 1950 issue of *Heat Engineering*. Write for a copy.

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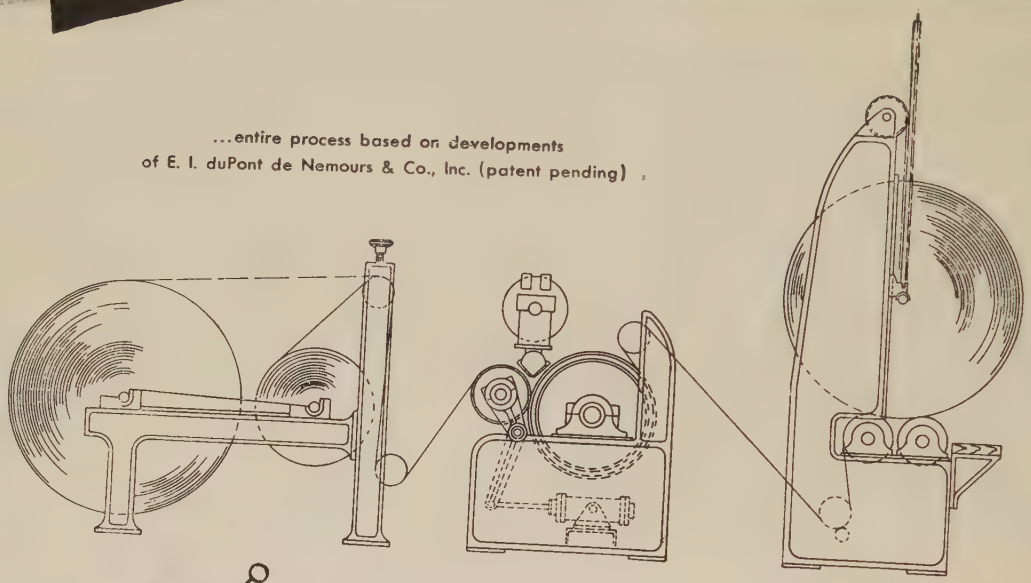

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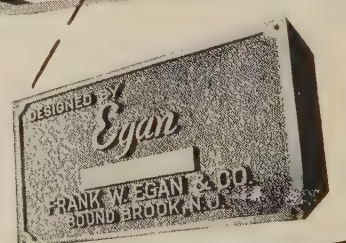


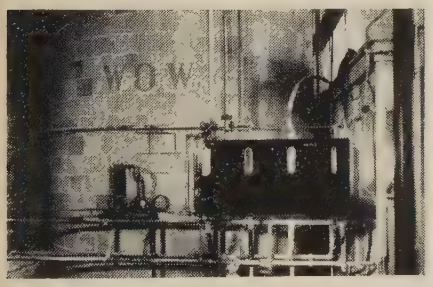
*Escanaba Paper Company Mill at Escanaba, Michigan*

# Escanaba increases brightness and cleanliness of its top-grade groundwood specialties with the

# DU PONT PEROXIDE PROCESS FOR GROUNDWOOD BLEACHING

In April, 1947, the Escanaba Paper Company in Escanaba, Michigan, installed this highly efficient peroxide process for the continuous bleaching of its spruce and balsam groundwood. The results in Escanaba's daily production of 75 tons of bleached pulp were immediately apparent. The peroxide bleached pulp showed increased brightness and cleanliness and improved formation on the machine. And the sheet displayed better printing properties.

The gain in brightness has been one of the outstanding features. Operating at 5% consistency and using 1.6 to 2.0% peroxide on the pulp, Escanaba has been able to get up to 10 points (G. E. Reflection Meter) increase in brightness. By replacing the unbleached groundwood in the paper furnish with peroxide bleached groundwood, the paper brightness is increased as much as 8 points.



The experience of the Escanaba Paper Company with this process is typical of the reports of paper mills in the U.S. and Canada now producing more and better paper with peroxide bleached groundwood.

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# A Study of the Pipe Friction Losses of Paper Stock Suspensions

W. BRECHT and H. HELLER

**This paper is an abridged report of the thesis submitted by H. Heller to the Technische Hochscule, Darmstadt, in partial fulfillment of the requirements for his doctor's degree. All tests on which this report is based were conducted in the pump testing room of the J. M. Voith shops, Heidenheim. A review of the American and European literature on the pipe friction loss of paper-stock suspensions is presented, and the disagreement and inconsistencies in the published data are pointed out. The lack of accurate descriptions of the testing methods and conditions, as well as the absence of complete technical description of the stock used, is particularly emphasized. A testing layout for determining pipe friction loss is described. Test results are presented showing the effect of the following variables on pipe friction loss: velocity, consistency, pipe diameter, pipe roughness, freeness, average fiber length, temperature, load, and various papermaking pulps. The test results are summarized and compared with the results obtained by previous investigators, and the value of the present material as a basis for further investigation is pointed out.**

Pipe friction loss represents the energy loss which must be applied to overcome the resistance to flow in a pipe. It is measured as the static pressure difference prevailing at two points distant from each other in a pipe line and referred to the same elevation, and is expressed in feet of water column per 100 feet of straight pipe.

The literature on this subject shows a number of works, and their results also show clearly enough that the pipe friction loss increases rapidly with increasing consistency of the suspension. Whether, however, this increase in the friction loss obeys a simple law as with water, or whether we here face relationships which are not yet susceptible to calculation, is a question which has been repeatedly posed, but which has never been satisfactorily answered.

The most extensive work on friction loss of fibrous pulp suspensions comes from Trimbey (*1*) and from Forrest and Grierson (*2*). Trimbey's tests were carried out in 1907 for various stock velocities and stock consistencies with pipes of four different diameters. Trimbey's work was with spiral riveted steel pipe which is seldom used today. Doty and Klosson (*1*) published these tests but without any description of the measuring arrangements or the accuracy obtained. It was merely indicated that the tests covered nearly exclusively the use of groundwood since Trimbey found a practically equal friction loss for groundwood and sulphite pulp. The values in the handbook "Cameron Hydraulic Data (*3*) which the Ingersoll-Rand Co. makes available, were taken from the work of Doty and Klosson and therefore also present the results obtained by Trimbey.

Forrest and Grierson also investigated the effect of the flow velocity. They used various consistencies of unbleached free sulphite pulp and of groundwood in four cast-iron pipes of different diameters. Differing from Trimbey, they established a substantially higher friction loss for groundwood than for sulphite pulp. From their work it furthermore appears that at low consistencies the friction loss of the suspensions is lower than that of water. The shape of the curves, as Forrest and Grierson have observed it, differs substantially from the results of all other investigators insofar as the former established with rising flow velocities a dropping and then again a partial rise of the friction loss. They explain this surprising occurrence by changing turbulence of the flow. In contrast to all other published papers, the two investigators have designated the slowness degree of the two stocks used, as well as describing in detail their test and measuring arrangements. As far as the accuracy obtained is concerned, it is reported that the results were verified by duplicate tests. Even though one must consider the researches by Forrest and Grierson to be the most comprehensive and the most careful studies made public until now, nevertheless the reported results limit themselves to the behavior of two kinds of stock, with no consideration having been given to the effect of average fiber length, slowness, temperature, etc.

In a paper on centrifugal pumps Bond (*4*) mentions curves on the friction loss of sulphite pulp but makes no explanation of their origin. He states various factors by which one must multiply the friction loss of sulphite pulp to obtain the friction loss for groundwood and for several fiber mixtures.

Brautlecht and Sethi (*5*) deal in their experiments only with consistencies up to about 1.6% and apply for the purpose the laws applicable to water. In agreement with Forrest and Grierson they find for highly diluted suspensions a lower friction loss than for water.

In a paper by Graef (*6*) curves from two foreign works are published which are compared with the curves by Forrest and Grierson. Graef explains that he could not learn much about the origin of these curves. He suspects that both works deal with friction loss of sulphate pulp in cast pipes since both experiments seem to show agreement in results. The curves reveal a substantially higher friction loss than Forrest and Grierson found even for groundwood.

The curves for the friction loss of stock of 4% con-

W. Brecht and H. Heller of The Technical College, Darmstadt, Germany
Originally published in *Wochenblatt für Papierfabrikation* vol. 66, nos. 14, 18, 20, 23, 25, 28, 31, 34, 38, 40 (1935). Translated and abridged by the Hydraulics Committee of The Technical Association of the Pulp and Paper Industry (1950).

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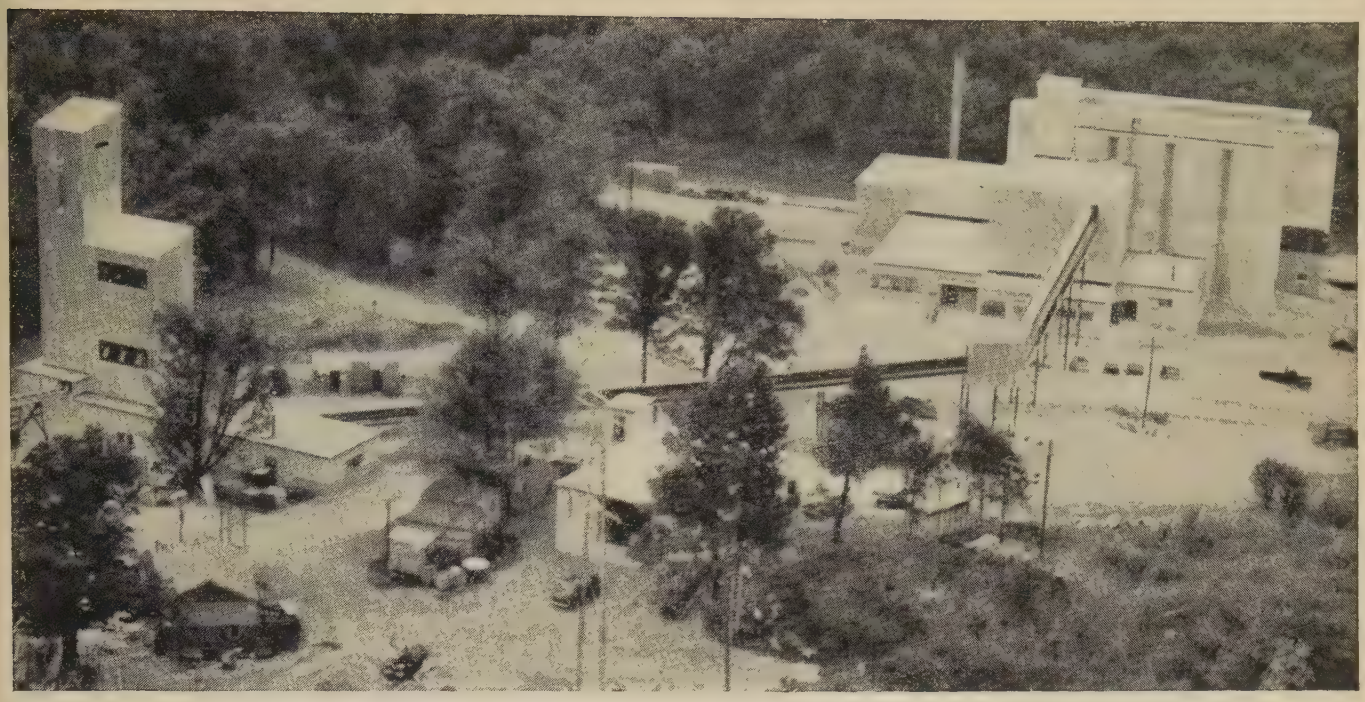

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sistency shown in the paper by Klosson (*8*) agree approximately with those by Trimbey (*1*). The values also refer to galvanized spiral-riveted steel pipes; the stock used is described in general terms as paper stock. Nothing is given regarding the test procedure or the accuracy of measurement.

Curves for the friction loss of stock suspensions were also issued by the firm Luth & Rosens Elektriska A. B. (*9*) in Stockholm which to our knowledge, however, have not been published in any journal. The data necessary for the use of these curves are scant, for it is not reported on what type of stock they are based, nor for which pipe materials they are valid, nor whether the given consistency refers to air-dry or moisture-free stock. The curves are substantially lower than all

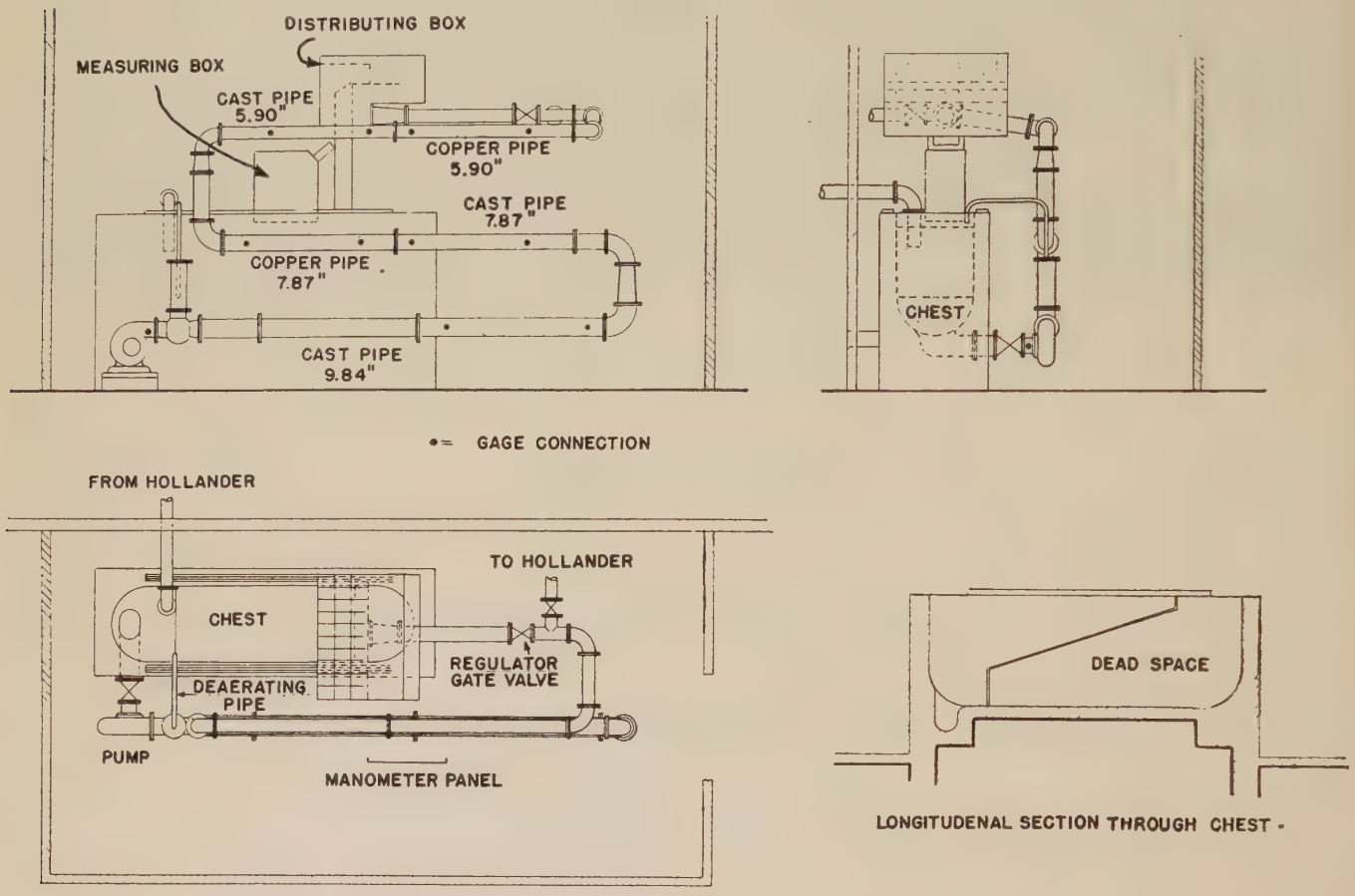


*Fig. 1. Testing arrangement*

other curves. There is no possibility of an explanation since nothing further is reported regarding the tests.

The values given by Muller (*10*) were taken from Trimbey's (*1*) work and were converted into the metric system.

Peirce (*11*) has also drawn up curves which give the relationship of the friction loss to the quantity pumped. In addition he reports that rags and kraft pulp have a higher friction loss than groundwood or esparto and that an addition of kaolin reduces the friction loss in spite of an increase in the total consistency.

Schmidt-Nielsen (*12*) describes experiments, which Flood conducted, to measure the viscosity (*13*) of diluted fiber suspension. Flood found that groundwood behaves like a suspension (*14*) and sulphite pulp like an emulsion (*14*), and that the viscosity varies with the pressure.

In agreement with Forrest and Grierson and with Brautlecht and Sethi, Schmidt-Nielsen mentions the interesting fact that the friction loss of highly diluted fiber suspensions is less than that of water. He explains this by assuming that with water turbulent flow prevails while with fiber suspensions it is laminar.

Smith (*15*) has also attempted to determine the viscosity of thick stock. His results are, however, faulty.

Sire (*16*) believes that the friction loss for stock can be obtained from that for water by multiplication with an appropriate factor and gives various factors therefor. That this procedure yields completely false results can be seen from all other known curves which clearly show that fiber suspensions in flow behave basically different than water. Sire also admits himself that the accuracy of this method is not very high and also mentions curves for the friction loss from which more exact values can be obtained.

The diagram (*17*) shown in the paper by Wintermeyer contains curves for the friction loss of stock suspensions to 7% consistency in a pipe of 9.84 inches diameter. The values are partly taken from the work of Trimbey (*1*), partly supplemented with experiments by Voith.

Summing up, one realizes first of all that the numerous published papers correspond to only very few really careful tests of interest. These few investigations are

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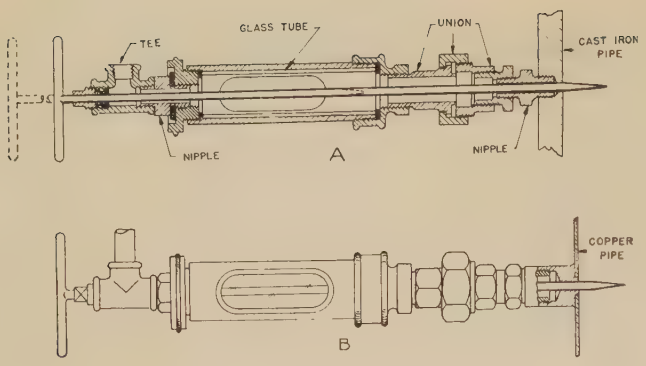


*Fig. 2. Junction of measuring and flow tube with stock lines*

also mainly directed toward the effect of the stock content, the flow velocity, and the pipe diameter, leading to results which do not agree with each other and which suffer from the lack of a sufficiently accurate description of the stock used. They above all do not permit a comprehensive picture of the difference in hydraulic behavior of the various half stuffs, and give no consideration whatever to the influence of the condition of the stock due to its preparation which the suspensions show and which might be expressed in degree of slowness or in average fiber length. The effects which result from changes in temperature have to the beginning of this work not been pursued at all, nor has the significance of the effect of the admixture of filler materials to the fiber suspensions on the hydraulic behavior.

In this work an effort is made to meet these lacks and to determine the pipe-friction loss of paper-stock suspensions through comprehensive experimental investigations for a wide range of flow velocities and an extensive area of consistencies and to clarify the relationships existing between the pipe friction, the type of moving or pumping and the type of moved or pumped suspension. We must disclaim any complete presentation of all results as they are set down in the original (*18*) paper, all essential observations will, however, be reported.

## THE TESTING LAYOUT

The over-all arrangement of the actual testing layout is shown in Fig. 1.

In an existing reinforced concrete chest which was too large for the work in hand, a separating wall was installed which reduced the useful content to about 160 cubic feet, insured a lively flow movement of the stock and thereby avoided the danger of stock segregation. A screw-type centrifugal pump of normal design (Type Voith 340/0/III-20) was connected to the chest through an airtight gate valve. At both the inlet and discharge of the pump was a gage connection which served to measure the static height $H$.

To deaerate the stock, a "Tee" was connected to the discharge of the pump which carried a pipe closed at the top. Into this pipe a pipe of smaller diameter reached downward and through which some stock, the amount of which could be regulated by a stopcock, was continuously recirculated into the chest to prevent plugging.

The piping system contained three cast pipes of different diameters and two copper pipes of different diameters. From the "Tee" which was connected to the pump, a conical increaser led to the lower pipe line which consisted of cast pipes of 9.84 inches diameter, followed by the others. The measuring points were arranged at the end opposite to the pump, in order to eliminate as far as possible flow disturbances which the pump could have caused when pumping water and highly diluted stock. The space available forced a two-fold turn around of the flow direction. They were installed in such a manner that the horizontal pipe lengths which served as testing lengths lay above one another, and the vertical connections were made through elbows and reducers. Above the lowest pipe line of 9.84 inches diameter lay the one with 7.87 inches diameter, and above that the pipe line with 5.90 inches diameter. In both lines the first pipe in the direction of flow was of cast iron, the second one of copper. The lengths of the test sections in the case of the cast-iron line of 9.84 inches diameter amounted to 8.86 feet, in the case of the cast iron and of the copper line of 7.87 inches diameter and also in the case of the copper pipe of 5.90 inches diameter each 7.9 feet, and in the case of the cast-iron pipe of 5.90 inches diameter 7.1 feet.

In the return line to the chest a gate valve was introduced which served to regulate the quantity handled. At the end of the return line was a distributing box and an arrangement for measuring the quantity handled. A branch line permitted the stock, after completion of one group of test, to be pumped to the Hollander for further changes in its degree of beating.

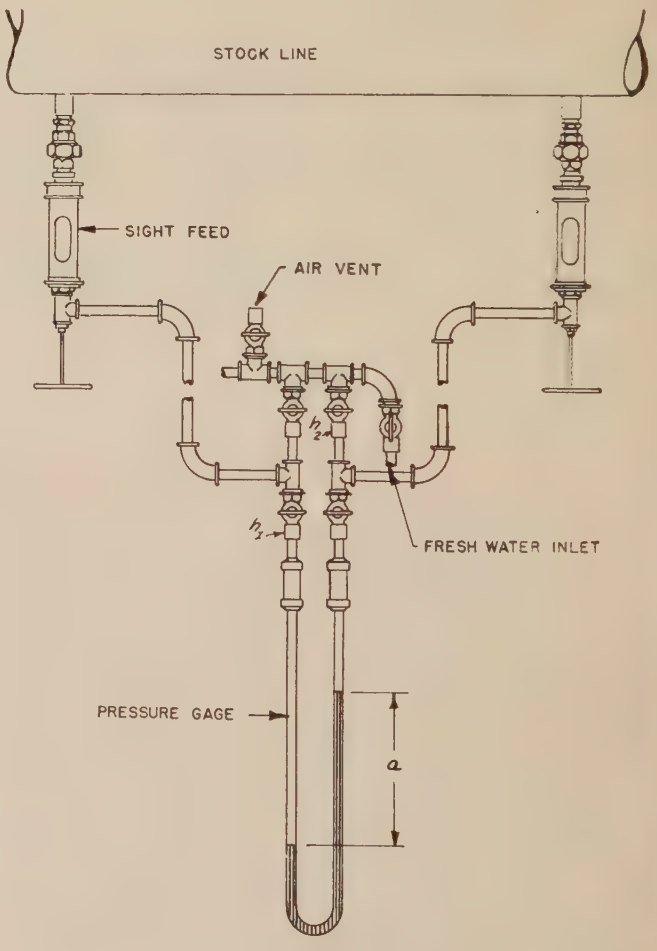


*Fig. 3. Junction of pressure gage with stock line*

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With the described testing arrangement, the effects of pipe friction losses, of flow velocity, stock consistency, pipe diameter, and pipe roughness—for unbleached sulphite and groundwood—were investigated. It was also used for studies of the effect of filler material, average fiber length, and degree of beating when handling unbleached sulphite pulp.

The measurements carried out on the friction loss of five additional different half-stuff suspensions after the completion of the above tests permitted a more practical arrangement of the test equipment. To eliminate the effect of the roughness due to different pipe materials, the new arrangement provided only copper pipes, whereby diameters of 7.87 and 5.90 inches were used. This arrangement also served to determine the effect of temperature.

In order to grasp the effect of the pipe diameter more clearly and distinctly than was possible with the first testing arrangement (Fig. 1) in which the different degrees of roughness of the pipe exerted a disturbing influence, a further change in the measuring arrangement was finally made. This time the test arrangement was equipped with four different diameters of smooth copper pipe. The results achieved with this arrangement were based on handling two half stuffs with varying consistencies and velocities.

## MEASURING DEVICES AND ACCURACY OF MEASUREMENTS

### *Pressure*

Friction loss was determined as the pressure drop between two stations on a pipe.

The measuring device, with the following modifications, which had been developed in the pump shop of J. M. Voith's machine works, followed a similar arrangement to that which Forrest and Grierson (*2*) independently used in their investigations.

The construction of the pressure measuring device is shown in Fig. 2. *A* shows the mounting of a measuring device in the wall of a cast-iron pipe and *B* is mounting in a copper tube.

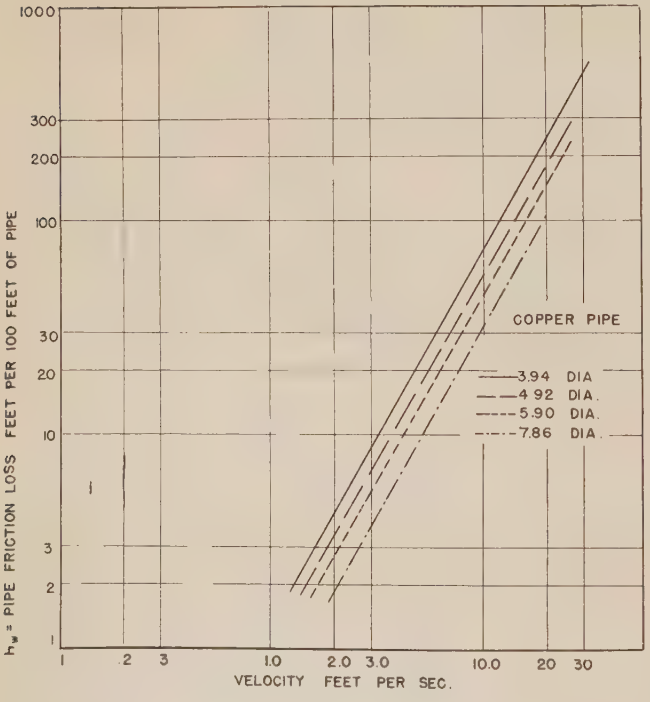


*Fig. 4. Friction loss vs. velocity for water*

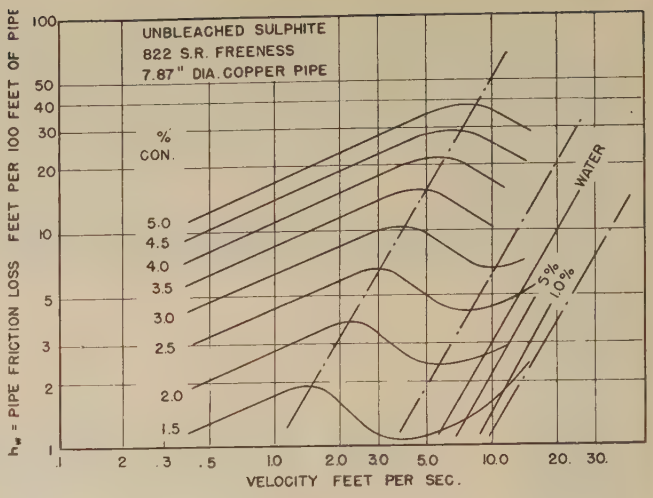


*Fig. 5. Friction loss vs. velocity for various consistencies*

To establish that no pulp was drawn into the measuring tube and that the manometer functioned without interference, a sight feed was attached to each pressure measuring device.

Through this sight feed a movable needle passed with which any blocking of the aperture could be pierced. Likewise the needle could be used to close the measuring tube. While pressure measurements with water flowing through a tube were customarily made with the pressure measuring station in a vertical plane through the axis of the stock line, one could work on the investigation of suspensions with one measuring station with only one pressure measurement; here we have provided a flow at each measuring station. The introduction of more pressure measuring devices to the same flow tube will give a warning if one measuring device is plugged, whereas by arranging more measuring stations, each with its own flow, an undesirable dilution of the suspension will result.

To eliminate the difficulties which, for pressure measurement, result from the coarse dispersion nature of the test suspensions, in the first experimental installation each pressure range was covered by a single manometer. Besides a distinct reduction in the likelihood of plugging so that the pressure drop between reading on the one and same pressure measuring device only varied between comparatively small limits, whereas between individual measuring devices there were considerable differences. Preparation for each measurement (Fig. 3) provided therefore that the cocks $h_1$ be closed and by opening cock $h_2$ the measuring tubes are rinsed with fresh water under 5 atmosphere pressures. Now by closing the cocks $h_2$ and opening the cocks $h_1$ a manometric reading was taken. In this way one was certain that no particles of pulp remained in the measuring tubes in which clean water was always present.

### *The Rate of Flow*

For the purpose of determining the flow per second the time of filling of a calibrated vessel was observed. From the pipe the discharge flows through a measuring box distributed evenly over a dam 78.8 inches wide. By means of adjustable valves the overflow could be

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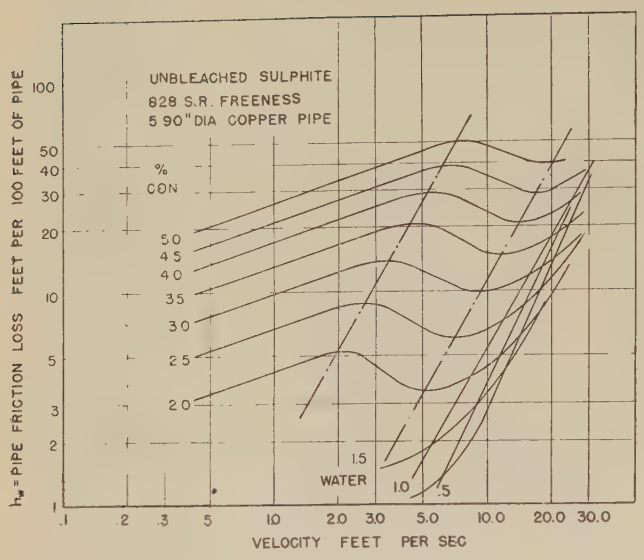


*Fig. 6. Friction loss vs. velocity for various consistencies*

returned either directly or through a measuring vessel in the collecting reservoir. The overflowing sheet was divided by nine tin partitions into 10 individual streams, each 7.87 inches broad. Each single stream could be diverted separately. It was now arranged so that each stream fraction, one after another, entered a measuring vessel during a constant fixed time interval. The quotient of the total quantity by the mean time for the overflowing stream fraction gives the flow per second.

For each test 10 valves were so arranged that the pulp flowed into the collecting chest. At the start of the test the first valve was quickly turned and a stopwatch started. The time interval for filling must be so selected that by the end of the tenth measurement the measuring chest has not overflowed. At small rates of flow two values were opened simultaneously.

## THE TEST RESULTS

### *The Loss Through Pipe Friction for Water*

For the purpose of obtaining a basis of reference for the investigations to be made with paper-stock suspensions, on the one hand, and data concerning the kind and magnitude of roughness of the pipes used, on the other hand, the losses through pipe friction for water were determined at the beginning and at the completion of the series of experiments made with pulps.

In all experiments the friction loss $h_w$ increased as the 1.72 to 1.73 power of the velocity. With smooth copper pipes friction decreased as the 1.27 to 1.28 power approximately, of pipe diameter $d$ (see Fig. 4). This agrees with the results obtained by other investigators. Reynolds (*25*) found an index of 1.723, Blasius stated it at 1.75 and Fromm at 1.73. The formula for the loss through friction is obtained with Reynolds' number of 1.723 as follows:

$$h_w = \psi \left(\frac{Re_5}{10}\right) - 0.277 \frac{l\ V^2}{d\ 2g}$$

Here the symbols mean:

$h_w$ in feet = loss through pipe friction
$Re = d.V/\nu$ = Reynolds' number
$\nu$ in square feet per second = kinematic viscosity
$l$ in feet = pipe length
$d$ in feet = inside diameter
$\psi$ = a friction coefficient dependent on the relative roughness

This formula should be applied only within the limits for which it has been determined, as any formula experimentally found. In the present case this means:

$d$ = 3.94 . . 9.84 inches
$V$ = 1.64 . . 39.4 feet per second
$Re$ = $10^5$ . . 1.3 . $10^6$

The following table shows the $\psi$ values determined by the experiments; it indicates also the "wall undulation" $S$ (*28*) introduced by Hopf.

The spread of the test results is evident from the column marked "Limit Values of 100 $\psi$."

Copper pipe shows a roughness factor which is greater by only 6 to 10% than that of completely smooth pipe. However, the first 5.90-inch pipe, which was somewhat dented and showed larger losses for this reason, is to be considered as out of line. The cast-iron pipes show very different "wall undulations," so

| *Test arrangement:* | 1 | | | | | 2 and 3 | | | |
|---|---|---|---|---|---|---|---|---|---|
| *Material:* | Copper | | Cast-iron | | | Copper | | | |
| *Diameter In.:* | *5.90* | *7.87* | *5.90* | *7.87* | *9.84* | *3.94* | *4.92* | *5.90* | *7.87* |
| Limit values of 100 $\psi$ | 2.45 | 2.06 | 5.48 | 3.30 | 2.98 | 1.94 | 2.12 | 1.99 | 2.00 |
| | 2.01 | 1.63 | 4.44 | 2.53 | 2.17 | 1.80 | 1.83 | 1.85 | 1.88 |
| Mean value of 100 $\psi$ | 2.22 | 1.85 | 4.90 | 2.86 | 2.53 | 1.88 | 1.90 | 1.94 | 1.93 |
| Wall undulation $S$ | 1.25 | 1.045 | 2.76 | 1.61 | 1.43 | 1.06 | 1.075 | 1.10 | 1.09 |

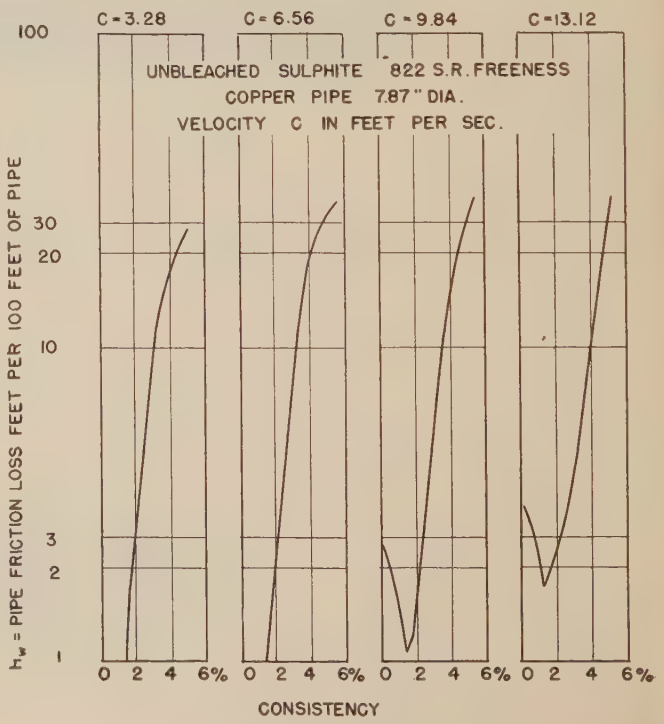


*Fig. 7. Friction loss vs. consistency for various velocities*

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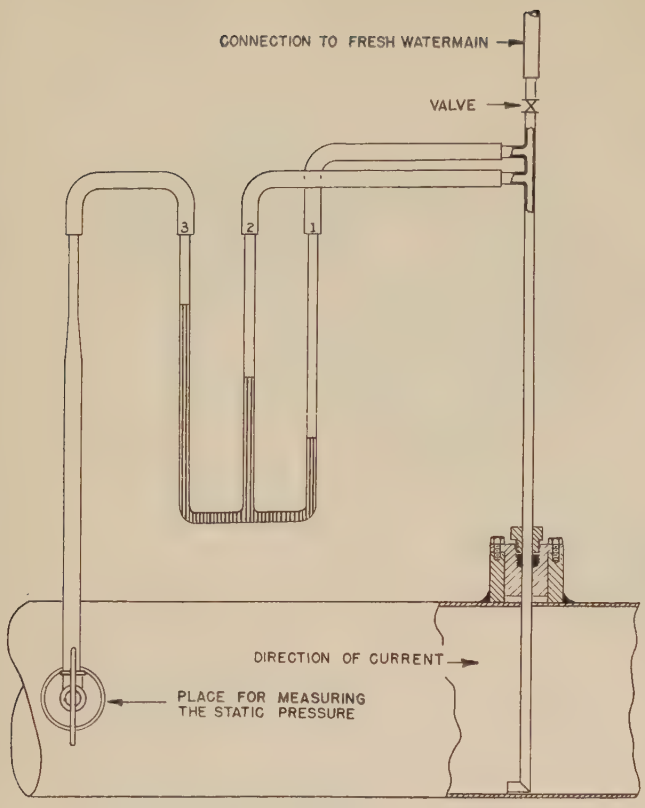


*Fig. 8. Counter-current Pitot tube*

that it is not possible to conclude from these tests that the friction increases with $d^{-1.277}$. It is rather to be supposed that the pipe walls had a different roughness.

***The Friction Loss of Fiber Suspensions***

In order to illustrate clearly the relationships found, the measured values of friction loss for the various densities of paper stock were plotted against the mean velocity in the pipe. For the purpose of obtaining a maximum of accuracy and clearness these curves were plotted at a fully logarithmic scale.

*The Influence of the Density of Paper Stock and of the Flow Velocity with Regard to Half Stuff (unbleached sulphite fiber IIa with copper pipe of 7.87-inch diameter).* In Fig. 5 the friction loss vs. velocity in the pipe is fully logarithmically plotted for the range of consistency of 0 to 5.0% moisture-free fiber. At the same consistency of paper stock the friction loss immediately increases from a velocity of 0, reaches a maximum, then drops again and rises anew at higher velocities, eventually reaching a point where the friction loss at an equal velocity becomes smaller than that of water. As it can be seen, the maxima and minima of the curves are on straight lines running parallel to the curve of water. In addition, all curves intersect the curve of water, tangent to a straight line, which is again parallel to the curve of water. This can be seen clearly from Fig. 6 showing the conditions for a copper pipe of 5.90 inches diameter, and follow a course similar to that of the curve of water as the velocity continues rising.

Figure 7 represents the influence of the consistency of paper stock. The fact that the friction loss of the suspensions at an equal velocity in the pipe decreases first, as the consistency increases, is particularly remarkable. With the curves plotted the smallest value is between 1.0 and 2.0% moisture-free consistency and moves the more to the range of higher consistencies the higher the flow velocity, while, in general, this strange behavior becomes even more marked the higher the flow velocity. After reaching the smallest value, which also increases as the velocity becomes greater, the pressure loss experiences an extremely steep increase at a rising consistency.

For water, the friction loss in the turbulent range, which here is in question, is proportional to the 1.723 power of the velocity. As one can see, this rule is not valid for solid suspensions.

The next study was to determine the velocity distribution across a pipe in a search for the cause of the maximum and minimum points.

We first worked with a simple Pitot-tube, built into a 5.90-inch copper pipe, with an entrance diameter of 8 mm., and supplied with a flushing apparatus similar to the one used for the apparatus measuring the static pressure.. In order to verify, with a higher degree of accuracy, the results obtained with this simple equipment, a counter current Pitot-tube was tried. The construction of the tube is shown schematically in Fig. 8. Flushing water was run through the tube during the experiments to prevent plugging of the tube.

The measurements which were taken with the counter current Pitot-tube verified through the whole range the results obtained with the simple Pitot-tube and made possible a considerable narrowing down of the errors in measurements which were particularly great for the lower velocities.

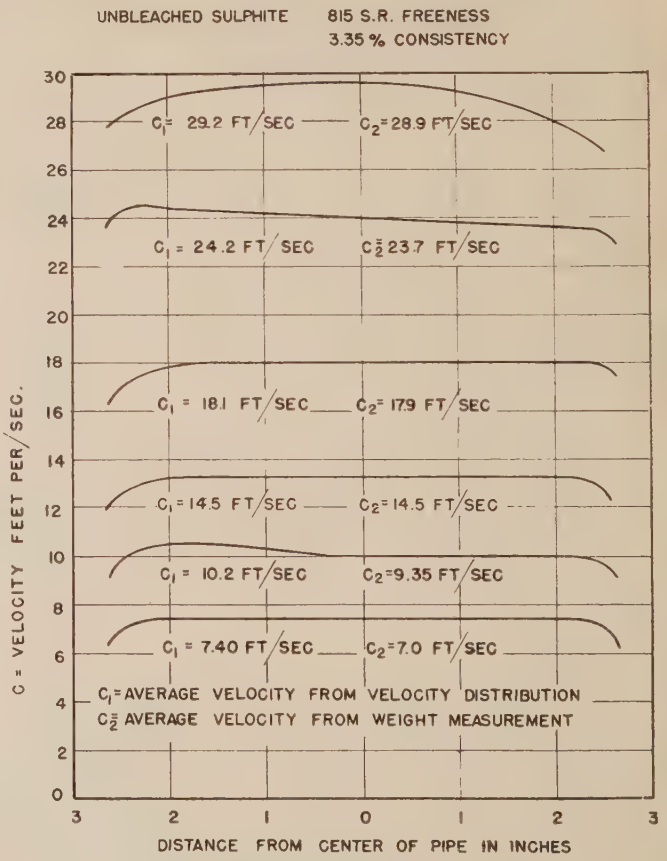


*Fig. 9. Velocity distribution in 5.90 inch diameter copper pipe measured with counter-current Pitot tube*

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The velocity distributions do not give any indication of the peculiar behavior of solid suspensions, and deviates, as Fig. 9 shows, rather radically from the tendencies which Forrest and Grierson give their hypothetical diagram. It must, however, be taken into consideration that the examined velocity distributions had not reached the region for maxima, as is shown in Fig. 6 which describes the behavior of an altogether similar system. According to this graph, the maximum for a consistency of 3.35% (moisture-free) occurs at approximately 4.18 feet per second, while the measurements, which must be considered to be fairly exact, only start at 7.08 feet per second.

Our attempts to disprove the differences in consistency over the cross section of the pipe existed, were unfortunately, experimentally unsuccessful. The differences in consistency which were found were all within the range of experimental error.

Perhaps the situation is that fiber suspensions behave as plastic bodies at low flow velocities and only take on the characteristic properties of fluidity at higher velocities (*28*). However, whatever the reason may be for the peculiar relation that exists between the friction losses of a paper-stock slurry and its flow velocity, it is now, as far as the industry is concerned, more important to get a thorough knowledge of what kind of a relationship exists than it is to find out what causes this relationship.

*The Influence of the Diameter of the Pipe.* The final determination of the influence of the diameter of the pipe was made with a simplified experimental apparatus equipped with four smooth copper pipes of 7.87, 5.90, 4.92, and 3.94 inches diameter. As in the case of the first experimental apparatus, the pipes were arranged one after another (in series).

The loss values as a function of the average velocity in the pipe for the four different diameters are shown in Fig. 10. The pulp was bleached straw pulp of 500 S. R. freeness and a consistency of 3.0%. As was expected, the friction loss was higher, the smaller the pipe diameter. The curves found for the individual pipe

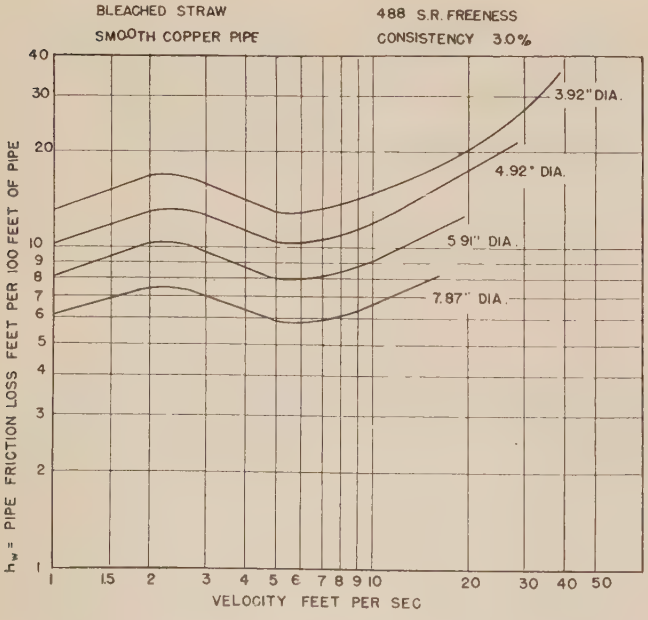



*Fig. 10. Friction loss vs. velocity for various pipe diameters*

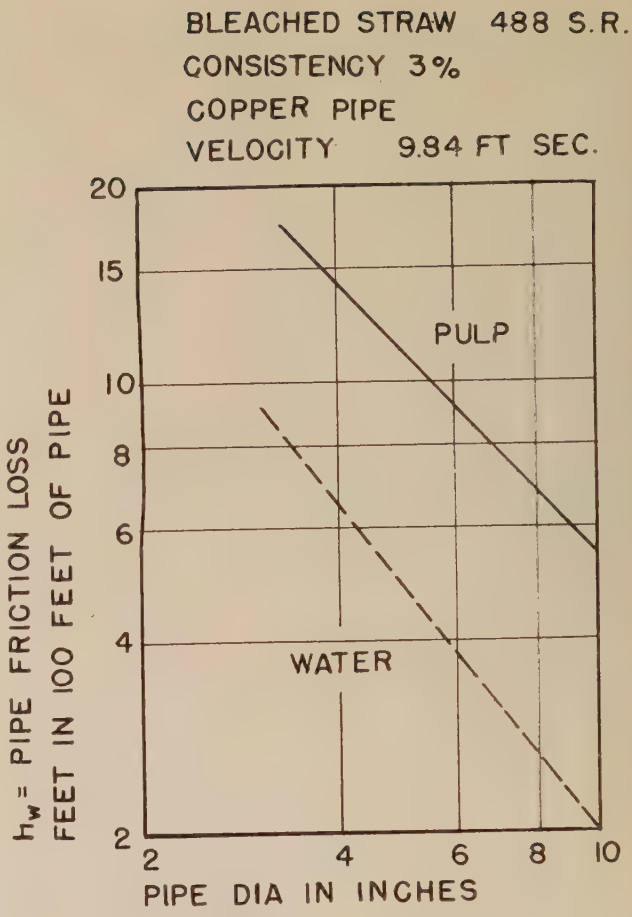



*Fig. 11. Friction loss vs. pipe diameter*

diameters showed similar shapes. The influence of the pipe diameter is shown more clearly in Fig. 11 than in Fig. 10 where the known line for water at the same velocity is also shown. In that figure, the nature of the relationship friction loss to pipe diameter at the same velocity is similar to that for water.

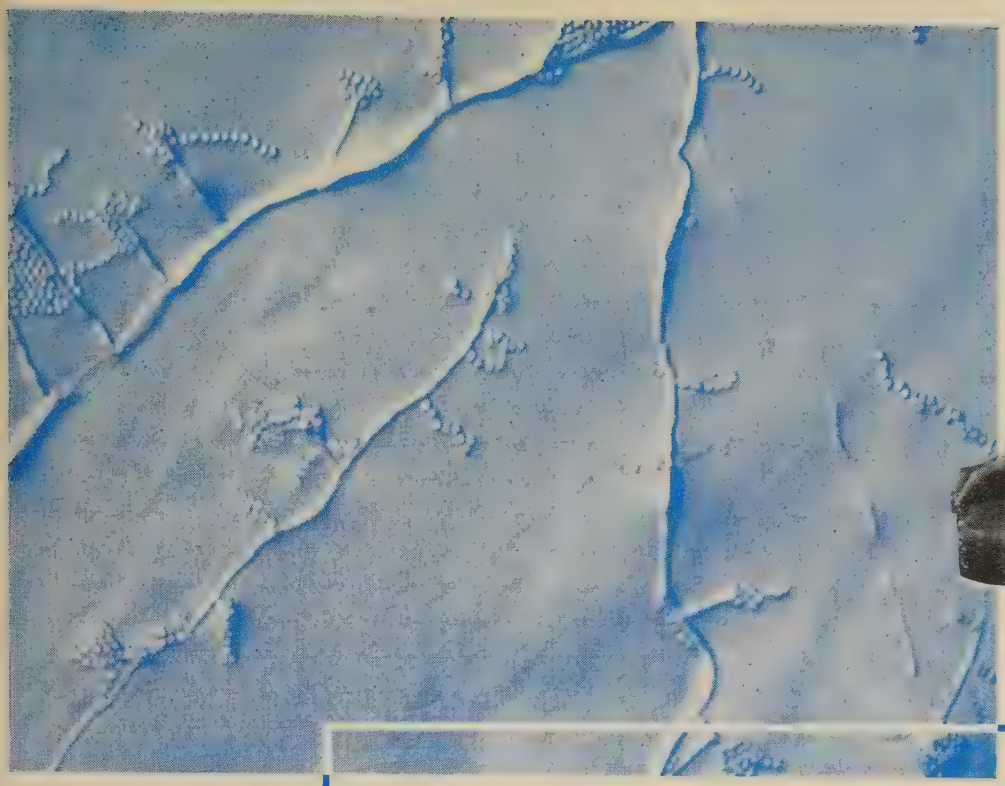
How the influence of the diameter changes with the use of suspensions of different consistencies is shown in Fig. 12. In the case of all velocities investigated, the rise of the loss in all of the pipes occurred about proportionally beyond the characteristic minimum loss.

*The Influence of the Pipe Roughness.* A comparison of the experimental results, which have been obtained under otherwise similar conditions but using cast iron and copper pipes of the same diameter, shows the important influence of the pipe surface (roughness). The comparisons were made with pipes of 5.90 inches diameter. The measurements made with water showed the following "wall undulation" values, which may be considered as a measurement of the pipe roughness.

| | 5.90-inch cast iron | 5.90-inch copper |
|---|---|---|
| Pipe waviness numbers: | 2.76 | 1.25 |

In Fig. 13, the difference of the pressure loss between the rough cast-iron pipe and the smooth copper pipe is shown as the ordinate. The figure shows the relationship for a specific stock (unbleached sulphite pulp of 822 S. R. freeness) at various consistencies and various velocities.

The results, which were obtained in the comparison of the rough and smooth pipes, are puzzling because their curves are found to lie below the "zero line" over a



*Left — Microphoto of Monilia (White), one of the slime-forming micro-organisms frequently found in paper mills and controlled by the Nalco System. Photos in Nalco Laboratories.*

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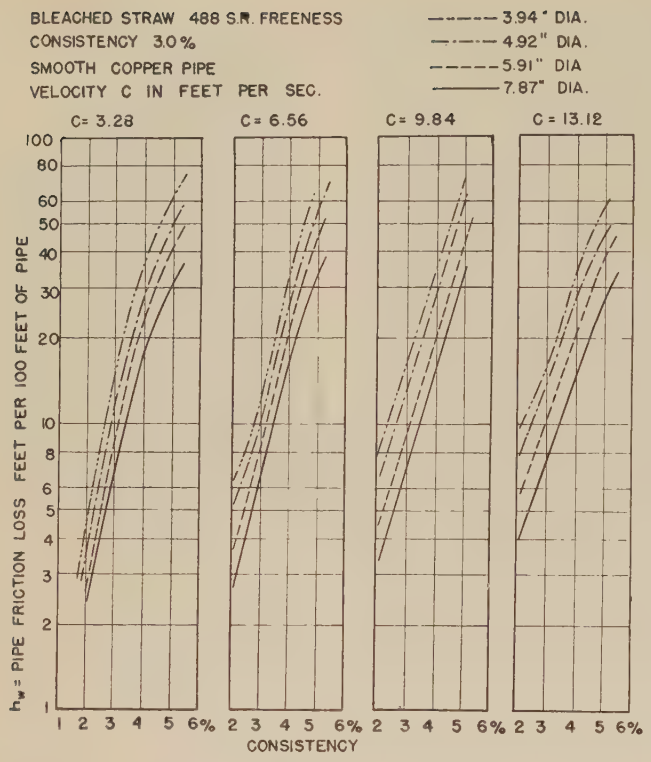


*Fig. 12. Friction loss vs. consistency for various pipe diameters*

large part of their course. At lower velocities the friction loss in cast-iron pipes as compared with the loss in smooth copper pipes is greater, the higher the consistency. A maximum is reached very quickly, however, which is in the vicinity of 1.54 feet per second in a pipe of 5.90 inches diameter. From this point on, the difference in loss becomes less, passes below the "zero line" at all consistencies and reaches a minimum which increases with consistency. After passing through the minimum, the curves turn back with increasing velocity to the area of positive values, at which, however, the picture changes insofar as it is now chiefly the lower consistencies at which the differences in pipe roughness manifest themselves the most. The curve, which illustrates the influence of the pipe roughness on the friction loss using water, shows no inflection points.

It is possible to explain this peculiar characteristic behavior of the suspensions, which differs so basically from that which would be expected on the basis of the corresponding relation of water, if one observes the relationship between the friction loss and the velocity of flow for exactly the same consistency of pulp, as it is shown for a pipe diameter of 5.90 inches in Fig. 6, and if one refers to the curves for comparison, which were obtained at the same diameter but with cast-iron pipe. Then one sees that in the case of the cast-iron pipe, the maximum pressure loss is reached at a lower velocity than in the copper pipe. During the time that the friction loss rises still higher in the copper pipe with increasing speed, it decreases in the cast-iron pipe to the minimum.

In summarizing, it can be said that with respect to the velocity of flow, the advantage falls to the smooth pipe, especially at the higher consistencies, and that the influence of pipe roughness shows itself to be different for pulp suspensions than for water in all ranges of velocity.

*The Influence of the Average Fiber Lengths.* The original unbleached sulphite pulp suspensions at hand were dewatered by means of a suction filter. This removed a relatively large amount of the short fiber fragments and increased the average fiber length of the remaining pulp to the high value of 1.83 mm. In contrast, a second suspension was prepared by exceedingly hard beating of the original pulp, which, without showing a real increase in slowness, as compared to the first suspension, had only about half the average fiber length, namely 0.94 mm.

It was shown that when the velocity was varied for the same consistency, or the consistency was varied for the same velocity, the friction loss exhibited no great differences. At a pipe diameter of 7.87 inches the suspension with the greater fiber length showed the higher friction over the entire velocity range investigated.

Although the span of both average fiber lengths at about the same degree of beating could be considered satisfactorily large in the comparison, it must be left undecided whether the results obtained, which as stated refer to coarse unbleached sulphite pulp, can be completely generalized.

*The Influence of the Degree of Beating.* The influence which the degree of beating exerts upon the friction loss in pipe was examined using three different pulps. In this case the entire range of the degree of beating occurring in practice (around 830 to 200 S. R. freeness) was covered.

In all experiments a marked influence of the degree of

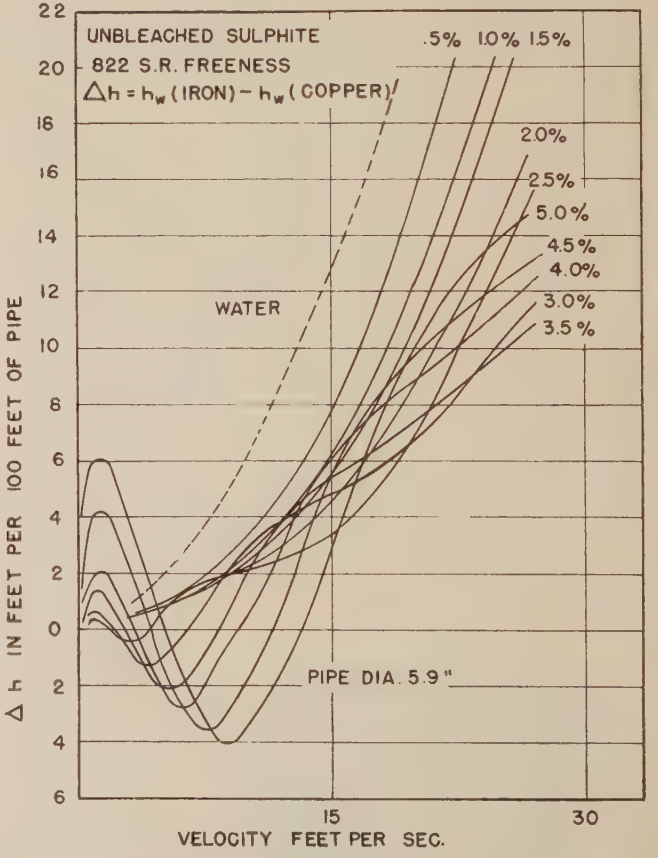


*Fig. 13. Influence of pipe roughness at various velocities and consistencies*

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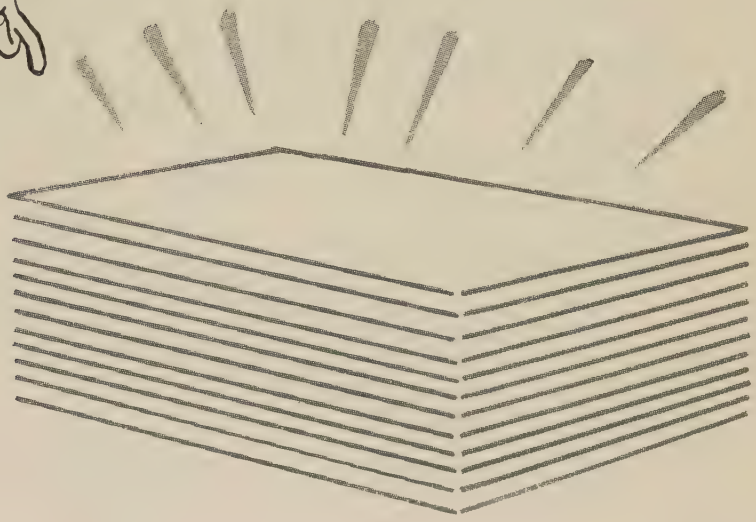

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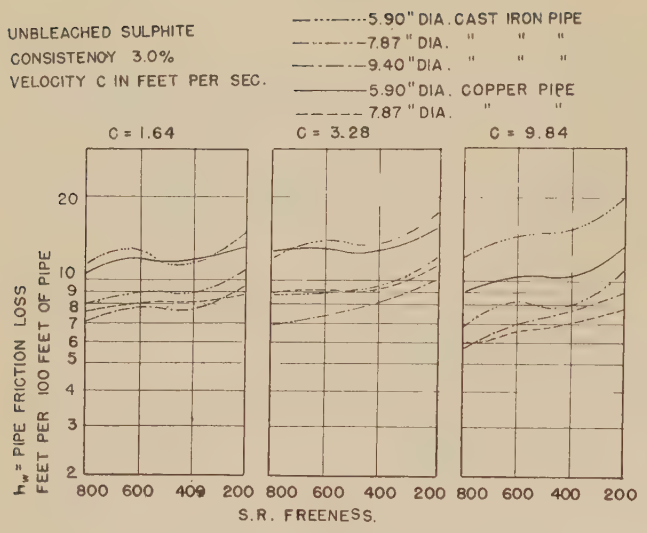

UNBLEACHED SULPHITE
CONSISTENCY 3.0%
VELOCITY C IN FEET PER SEC.
5.90" DIA. CAST IRON PIPE
7.87" DIA. " " "
9.40" DIA. " " "
5.90" DIA. COPPER PIPE
7.87" DIA. " "
C = 1.64
C = 3.28
C = 9.84
$h_w$ = PIPE FRICTION LOSS FEET PER 100 FEET OF PIPE
S.R. FREENESS.

*Fig. 14. Friction loss vs. degree of beating*

beating was found which was of a rather complex nature.

Figure 14 shows the change in friction loss which an unbleached sulphite pulp exhibited when the suspension (at various degrees of beating) is pumped through pipes of varying diameters and of different degrees of roughness. Under otherwise similar conditions, the pressure loss rises with increase in degree of beating. Besides, this rise takes place in a rather vigorous manner up to about 620 S. R. freeness. Then it levels off with increased rise in beating degree up to about 450 S. R. freeness and then undergoes another increase with continued rise of beating degree. The size of the pipe diameter takes on a rather important influence on the manner of the pressure loss, while the roughness of the walls of the pipes produces a real difference between the friction loss of the smooth and rough pipe only in the region of the higher velocities.

Figure 15 illustrates the important fact that friction at a given degree of beating increases with increasing consistency. It also shows that at approximately equal freeness the average fiber length has a small but significant influence on the whole relationship of the effect of consistency on friction loss. At higher consistencies the effect of fiber length on friction loss is relatively greater than at lower consistencies. The longer fibered pulps appear to require greater energy to overcome pipe friction than do shorter fibered pulps, although the latter may possess lower freeness.

Figure 16 shows data for unbleached sulphite, unbleached sulphate, and bleached sulphite pulps tested at a velocity of 3.28 feet per second and a consistency of 3.0%. These data show that the degree of beating has a very marked effect which varies depending on the kind of pulp.

While the unbleached sulphate pulp exhibits a substantially higher friction loss than the unbleached sulphite pulp, the relative effect of the degree of beating is about the same and neither shows much tendency to drop with decreasing freeness at this velocity. However, the bleached sulphite pulp behaved entirely

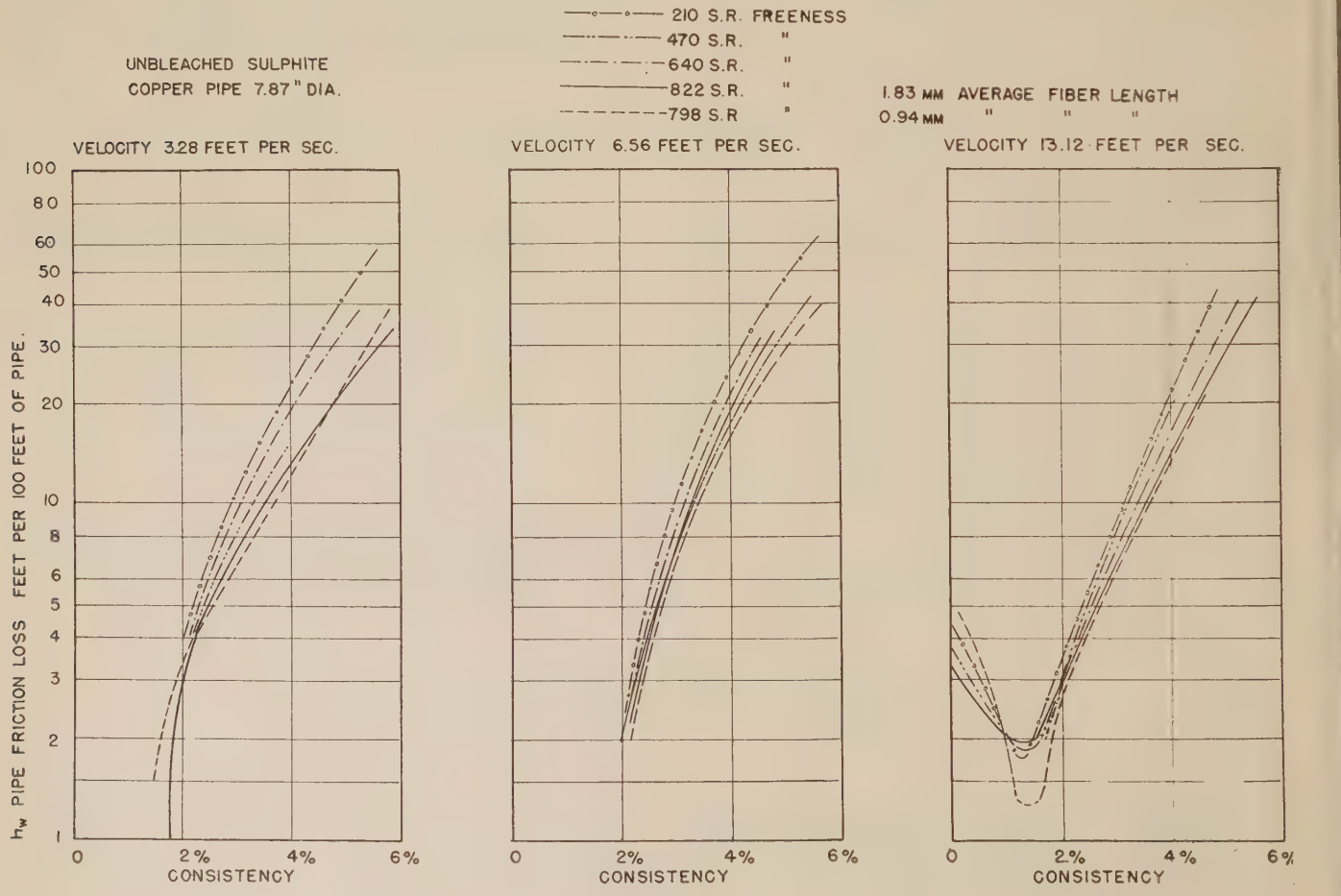
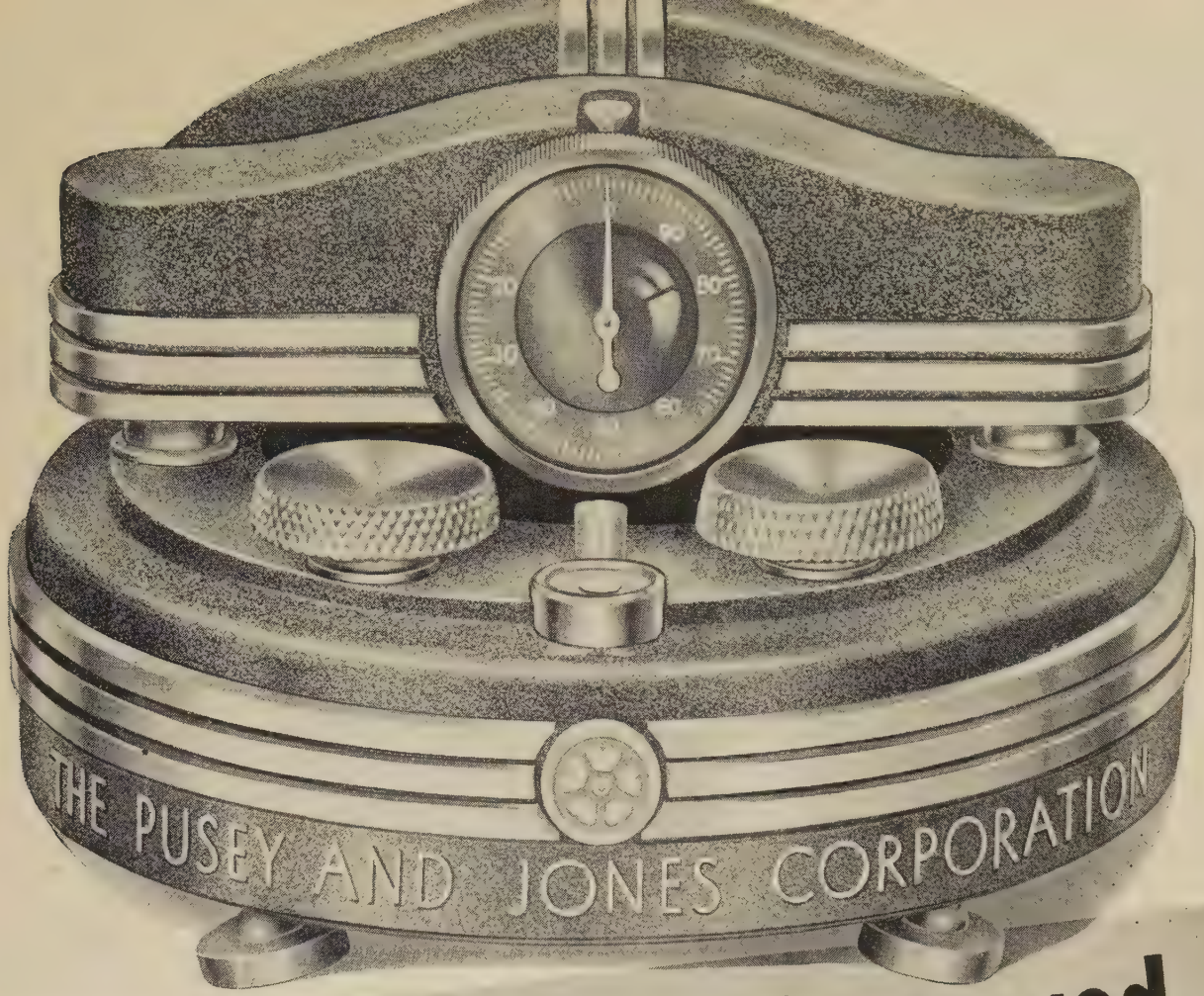



*Fig. 15. Pipe friction loss vs. consistency for various freenesses and velocities*

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differently. In this case the friction loss decreases with increasing degree of beating up to 300 S. R. freeness and then increases above this value. This raises the question of how unbleached sulphate pulp will behave at higher velocities.

Figures 17–19 show the relationships of friction loss values to velocity in 7.87-inch diameter copper pipe for the above discussed pulps at several freenesses at a consistency of 3%. These data indicate that the influence of freeness on friction loss is not a simple relationship. The curves cross and the relative values are therefore quite different at different ranges of velocity. The unbleached sulphite and unbleached sulphate pulps show quite similar behavior in the freeness range below 670 S. R. freeness. However, at higher freeness their behavior is considerably different. In this region the friction loss curve for the unbleached sulphate pulp reaches its maximum at a very much higher velocity and has a much higher maximum than that for the unbleached sulphite pulp. In the case of the bleached sulphite pulp the friction losses for the various freenesses in the lower velocity range behave similarly to those of the other two pulps with the exception that they reach their maximum values somewhat earlier. Further, similar to the unbleached sulphate pulp the friction losses of the bleached sulphite pulp at high freeness are highest and reach their maxima at the higher velocities.

It is apparently to be concluded from the above that the effect of the degree of beating on pipe friction loss is of a different nature for different pulps and that for any one pulp certain differences in this relationship are to be expected, depending on the condition of the pulp. Unbleached sulphite pulp showed that with an increase in the degree of beating on the whole there was a corresponding clear cut and definite increase in the friction loss which is especially true at higher consistencies. Further work should be done to follow up this and provide data taken under controlled conditions to show the effect of pipe diameter and roughness of pipe surface.

*The Influence of Temperature.* W. N. Baker (*28*), who on the occasion of a lecture discussion, criticized the experimental determination of frictional loss, stated that measurements of the frictional loss in a

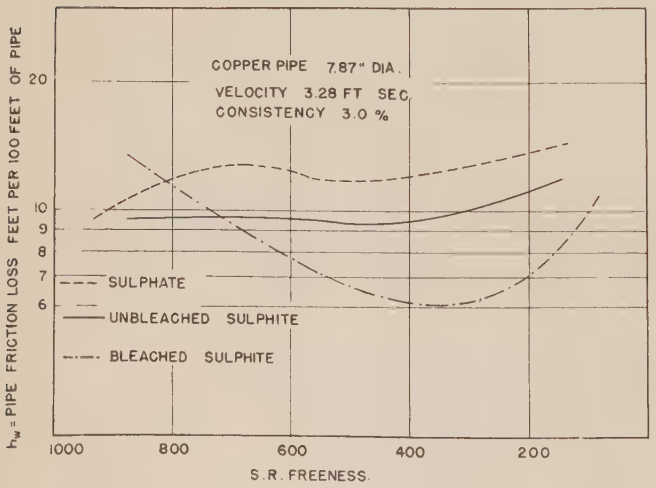


*Fig. 16. Pipe friction loss vs. freeness for various pulps*

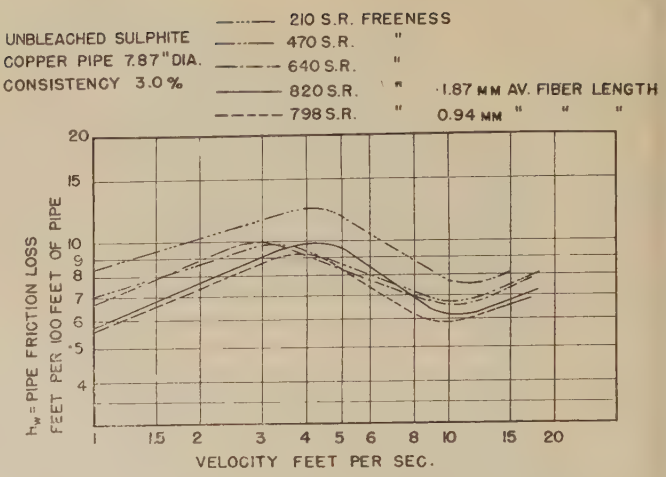


*Fig. 17. Pipe friction loss vs. velocity for various freenesses and fiber lengths*

laboratory are of questionable value since the materials experience an uncontrollable increase in their hydration, due to the constant pumping, so that no comparable results can be achieved.

Preliminary tests for the present work have shown that the hydration of the suspension increases with the duration of agitation. And, further, the lower the level of hydration at the beginning of the pumping, and the higher the pumping head, the greater will be the gain in hydration.

The amount of time necessary for the actual tests was so slight that the increase in degree of hydration would not be appreciable and consequently would not affect the accuracy of the measurements. The influence of the temperature was somewhat different; it showed a rise that resulted in a decrease in the friction loss factor.

With the first test arrangement using bleached sulphite, the influence of the temperature was followed in detail.

**Table I. Temperature Coefficients**

| *Pipe diameter, in.* | *Velocity, ft./sec.* | *Temperature Coeff.* | *Pipe diameter, in.* | *Velocity, ft./sec.* | *Temperature Coeff.* |
|---|---|---|---|---|---|
| Bleached sulphite | | 740 S. R. freeness | | 5.4% consistency | |
| 5.90 | 4.1 | 0.0119 | 7.87 | 2.3 | 0.0114 |
| | 8.2 | 0.0114 | | 4.6 | 0.0107 |
| | 14.7 | 0.0114 | | 8.2 | 0.0108 |
| Average | | 0.0116 | | | 0.0110 |
| Bleached sulphite | | 145 S. R. freeness | | 4.9% consistency | |
| 5.90 | 0.98 | 0.0058 | 7.87 | 0.98 | 0.0054 |
| | 5.9 | 0.0054 | | 3.9 | 0.0052 |
| | 16.4 | 0.0056 | | 9.8 | 0.0050 |
| Average | | 0.0056 | | | 0.0052 |
| Bleached sulphite | | 125 S. R. freeness | | 4.1% consistency | |
| 5.90 | 0.98 | 0.0039 | 7.87 | 0.98 | 0.0038 |
| | 5.9 | 0.0039 | | 3.9 | 0.0036 |
| | 16.4 | 0.0041 | | 9.8 | 0.0037 |
| Average | | 0.0040 | | | 0.0037 |

As Fig. 20 shows, there is a linear drop in the frictional loss with rising temperature. The amount of drop is not as great with slow materials as with the freer. The stock was pumped through a smooth copper pipe having a diameter of 5.90 inches at a velocity of 6.56

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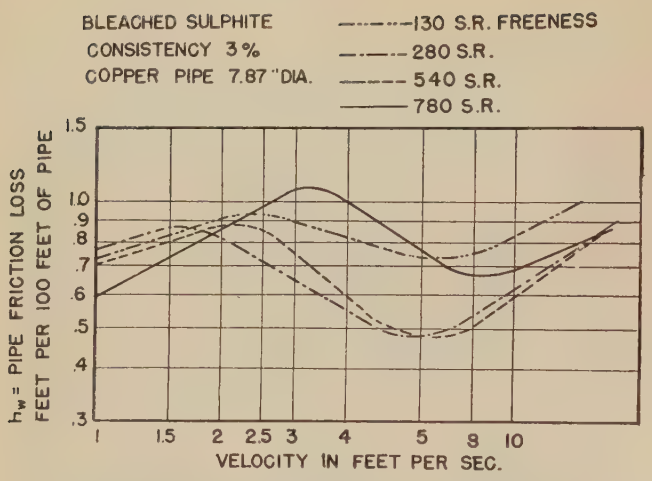



*Fig. 18. Pipe friction loss vs. velocity for various freenesses*

feet per second. With a change in temperature of from 15 to 40°C. there was a drop in friction loss. The stock with a 740 S. R. freeness and a consistency of 5.4% dropped from 228 to 167 feet per 100 feet of pipe. Stock with a 130 S. R. freeness and a consistency of 4.9% dropped from 195 to 171 feet per 100 feet of pipe.

Under identical conditions the friction minimizing action of a rise in temperature is stronger, the higher the consistency of the suspension.

Figure 22 shows how the influence of the temperature was found in the case of the bleached sulphite (130 S. R. freeness) at two different consistencies and two different pipe diameters for the velocity range. One can see the influence is the same in the entire velocity range.

In Table I, the temperature coefficients for the tested ranges and pipe diameters are shown as derived from the following equations:

$h_w' = h_w'' [1 - h_t (t' - t'')]$
$h_w$ = Friction loss at the temperature $t'$
$h_w''$ = Friction loss at the temperature $t''$ $(t'' < t')$
$\zeta_t$ = Temperature co-efficient

The friction losses necessary for the computation were taken from Fig. 22 using the curves for 780 S. R. freeness.

The results show that the coefficients under otherwise identical conditions for all velocities and at both pipe diameters remain constant for all practical purposes.

*Influence of the Material.* The varied results that the suspensions of one or the other halfstuffs showed led to the conclusion that differences in halfstuffs, other conditions being identical, result in differences in pipe friction loss. The following materials were tested:

| | *S. R. freeness* |
|---|---|
| Unbleached sulphite IIA | 822 |
| Bleached sulphite (soft) | 780 |
| Unbleached sulphate | 860 |
| Bleached straw | 500 |
| Groundwood | 280 |
| Cooked groundwood | 480 |
| Unbleached straw | 800 |

All tests were made using 7.87-inch diameter copper pipe.

Figure 23 shows the difference in the amount of friction loss for materials identical in consistency at various rates of flow. Further, it shows with what great inconsistency the friction losses of the individual pulps change with a change in the rate of flow.

At rates of flow up to 3.28 feet per second and with a consistency of 3.0% unbleached straw pulp shows by far the least friction loss. Bleached straw pulp is somewhat higher.

The friction loss of beaten unbleached sulphite lies like that of bleached sulphite and unbleached sulphite under the pipe loss of straw cellulose in the low velocity bracket. At velocities of over 1.64 feet per second, however, they are somewhat over that of straw cellulose.

While, with a rise of over 3.28 feet per second, the friction loss of the sulphite stock falls rapidly.

*The Effect of Clay Content upon the Friction Loss of Water.* By adding clay to the water circulating in the pipe system aqueous clay suspensions of different concentrations were produced, and in employing the first-used test setup the pressure losses were determined in connection with different rates of flow, pipes of different diameters, and different materials. In Table III there are computed the basic values for the different pipes and the different clay contents. In multiplying the friction loss of water with these values the friction losses of the different clay suspensions are obtained. Since the curves, indicating the friction losses of the suspensions and plotted logarithmically are lines parallel to the water curves, the computation values remain the same for all velocities and thus it suffices to give it for one velocity only. For each measurement taken for a certain concentration, average values of the computation figures were established without giving consideration to the different pipe diameters and pipe materials, this method appearing to be permissible when it was found that the variations from the average values were lying within the margin of error. The fact was established that by adding clay to the water the friction loss was slightly increased, this increase being somewhat more pronounced with the increase in the consistency.

*The Effect of the Clay Content upon the Friction Loss of Pulp Suspensions.* Groundwood was used as the fibrous material for this series of tests since the hydration factor of groundwood remains substantially constant during pumping in contrast to chemical pulp, furthermore, it was deemed advantageous to examine

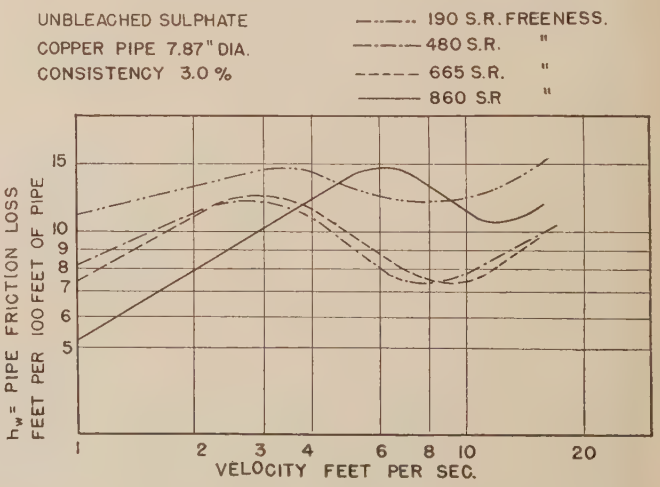
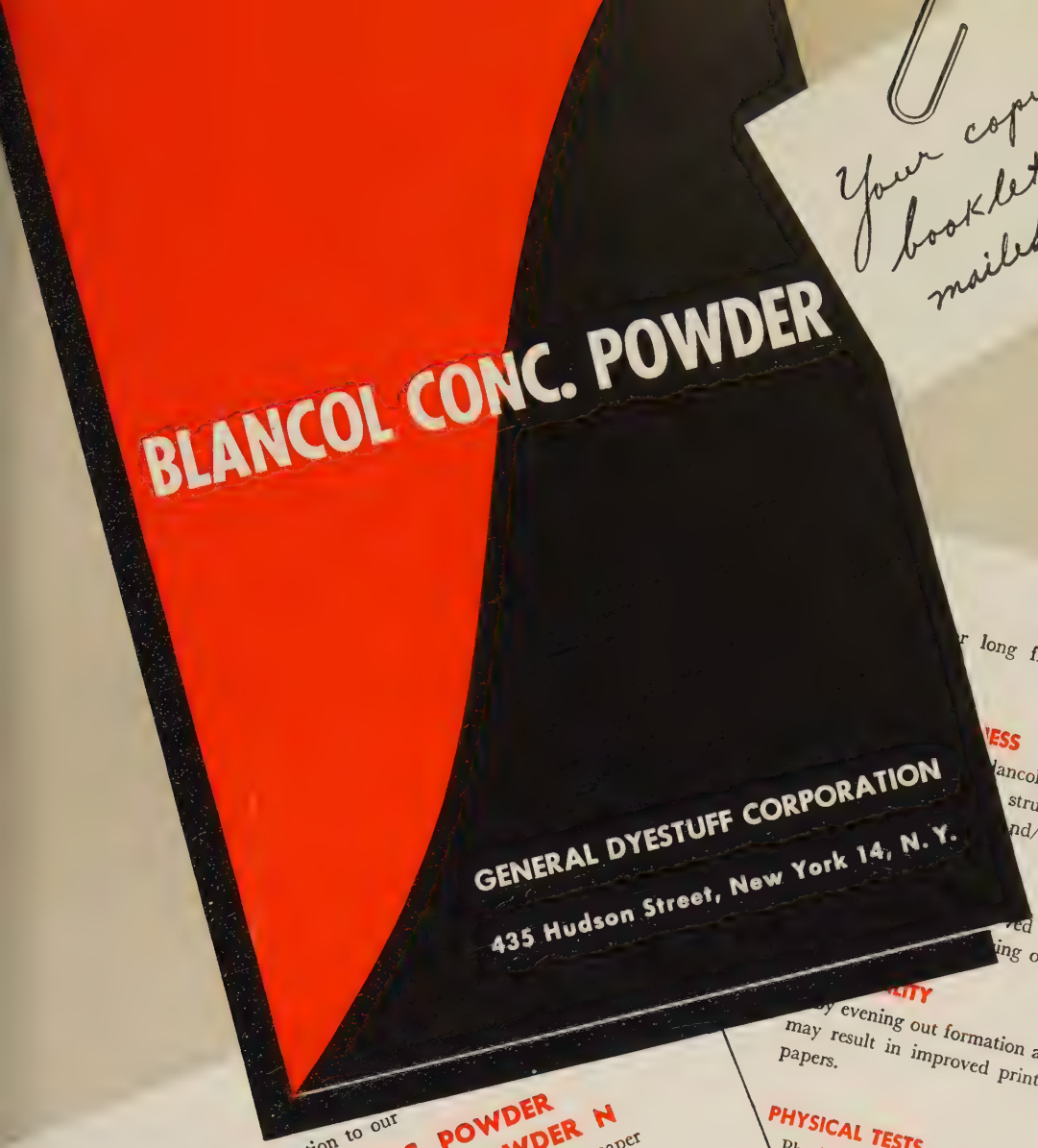



*Fig. 19. Pipe friction loss vs. velocity for various freenesses*

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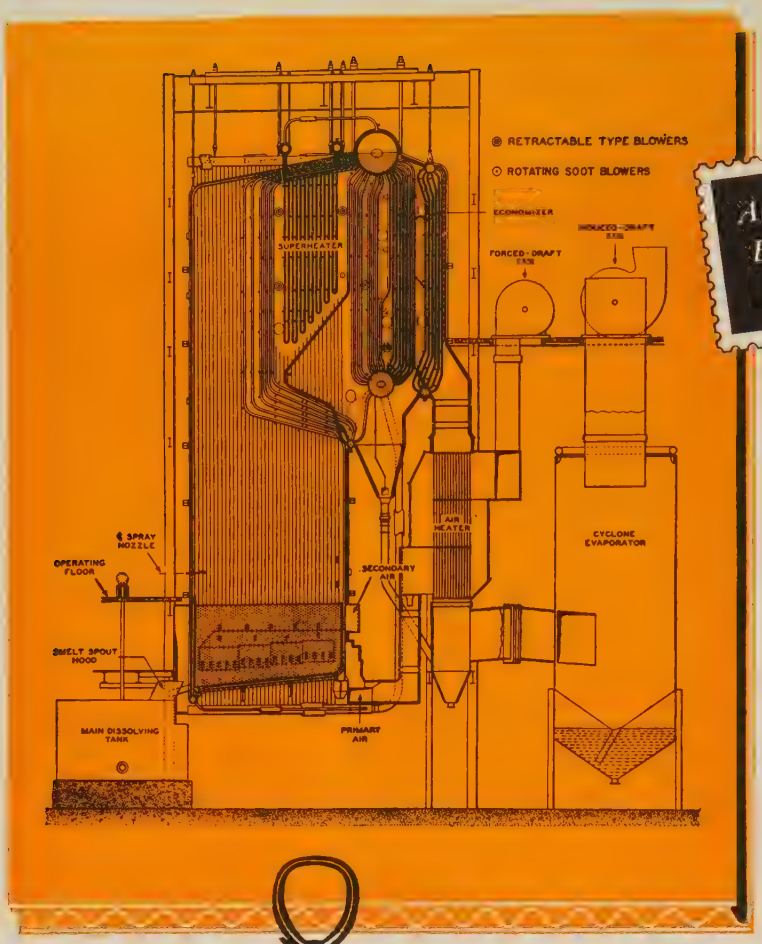


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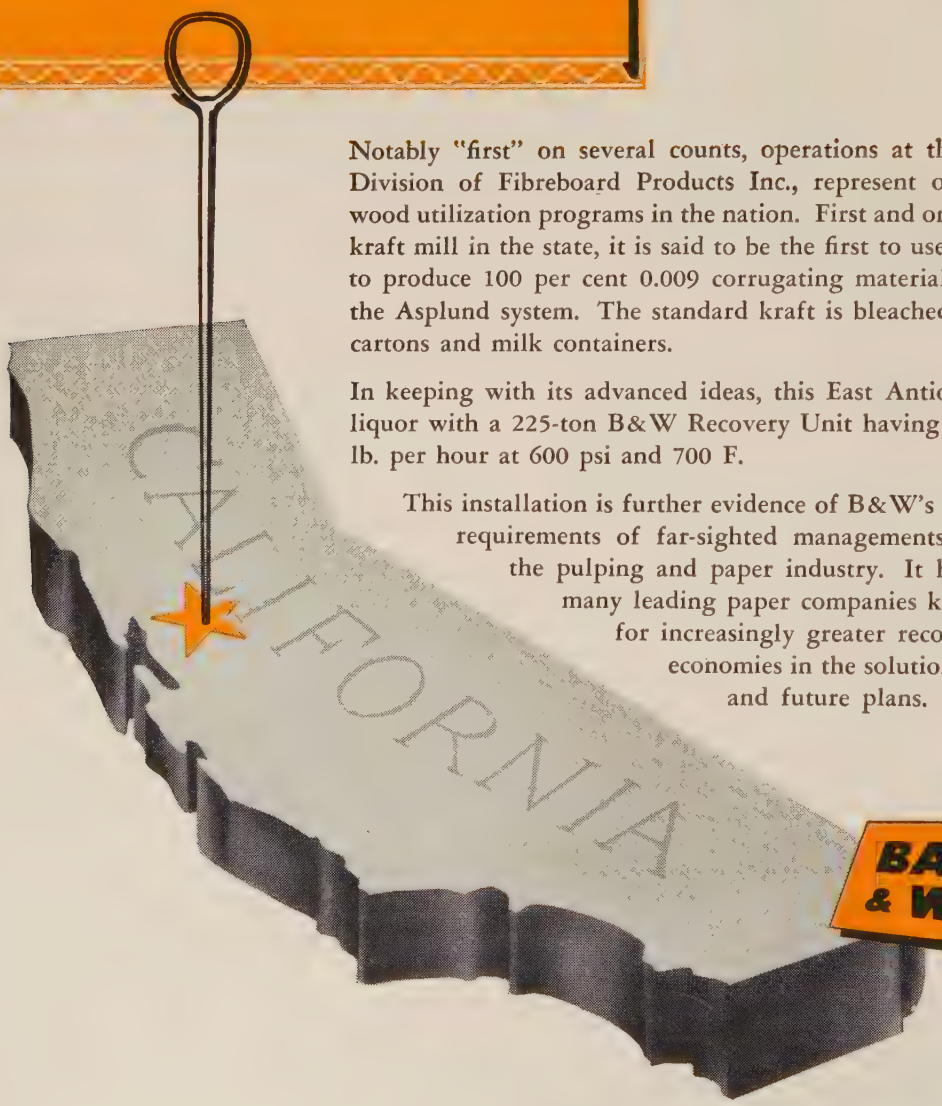


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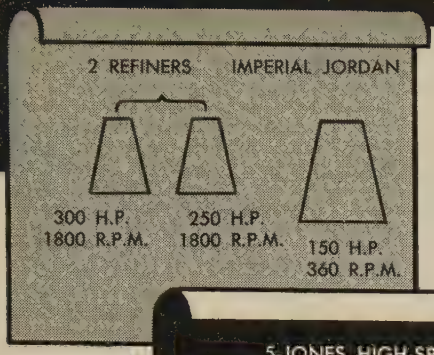


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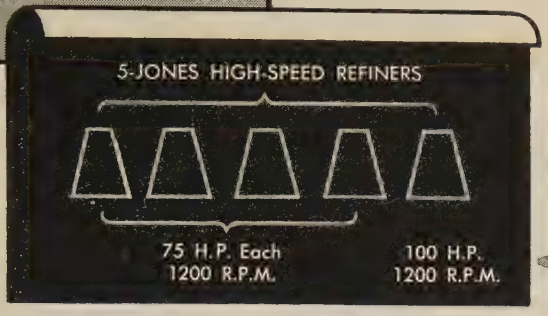


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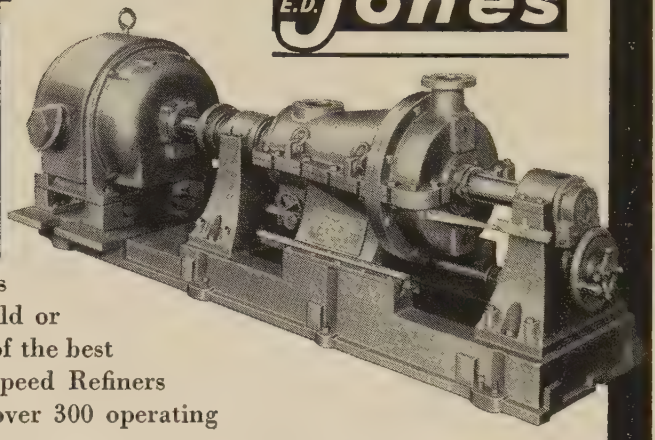

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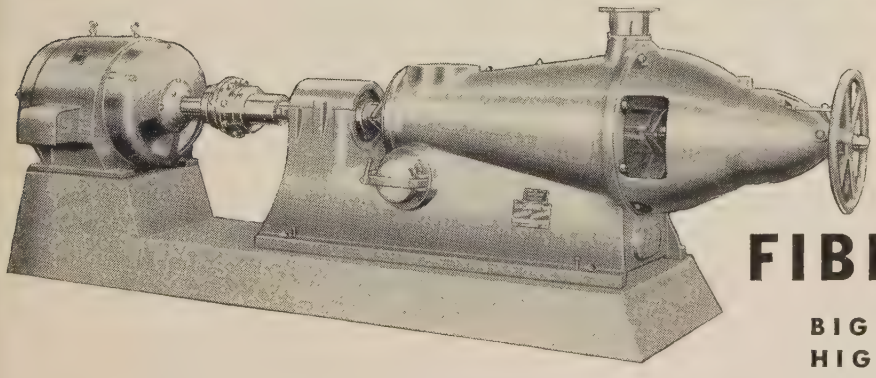

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the effect of the filler content when the filler is mixed with a fibrous material which in itself strongly affects pipe friction loss. Moreover, the use of groundwood, in view of its high pipe friction, assures substantial pressure variations and thus provides favorable measuring conditions. Last but not least, in view of the fact that this material is present in many, if not most of the papers having a clay content, its use for these tests seemed to be preferable.

In the first test group, the specific clay content which indicates the parts by weight of the filler to 100 parts by weight of fibrous material, was kept constant at 26.5%. The total consistency of the suspension was varied. Figure 25 illustrates the results obtained when using a 7.27-inch copper pipe. Taking four different rates of flow the friction losses are plotted against various consistencies of the pulp suspensions, of which, in each case, one is a groundwood suspension with filler (26.5 parts by weight of clay to 100 parts by weight of moisture-free pulp) and the other, in comparison, is a groundwood suspension without filler. The filler, in every instance, brought about a reduction of the pipe friction, which is about the same for the different velocities but which, at first, increases with an increasing consistency of the suspension and then gradually attains a substantially constant relation to the friction loss of the suspension not containing a filler.

**Table III. Computation Values for the Effect of Various Additions of Clay on the Pipe Friction Loss for Water**

| Pipe: Material: / Diameter, In.: | Cast iron 5.90 | Cast iron 7.87 | Cast iron 9.84 | Copper 5.90 | Copper 7.87 | Average |
|---|---|---|---|---|---|---|
| $h_w$—Water | 16.4 | 1.92 | 0.405 | 7.3 | 1.24 | |
| $h_w$—3.5% Clay | 18.0 | 2.05 | 0.433 | 8.0 | 1.35 | |
| Computation value | 1.095 | 1.07 | 1.07 | 1.105 | 1.09 | 1.09 |
| $h_w$—Water | 16.2 | 1.88 | 0.398 | 7.15 | 1.225 | |
| $h_w$—5.5% Clay | 18.2 | 2.10 | 0.44 | 8.15 | 1.39 | |
| Computation value | 1.122 | 1.113 | 1.105 | 1.14 | 1.135 | 1.123 |
| $h_w$—Water | 15.9 | 1.85 | 0.39 | 7.02 | 1.205 | |
| $h_w$—9.5% Clay | 18.1 | 2.20 | 0.45 | 8.20 | 1.39 | |
| Computation value | 1.14 | 1.185 | 1.155 | 1.17 | 1.155 | 1.161 |
| $h_w$—Water | 15.85 | 1.84 | 0.388 | 6.99 | 1.195 | |
| $h_w$—12.5% Clay | 17.9 | 2.15 | 0.43 | 8.00 | 1.35 | |
| Computation value | 1.13 | 1.165 | 1.11 | 1.145 | 1.13 | 1.136 |

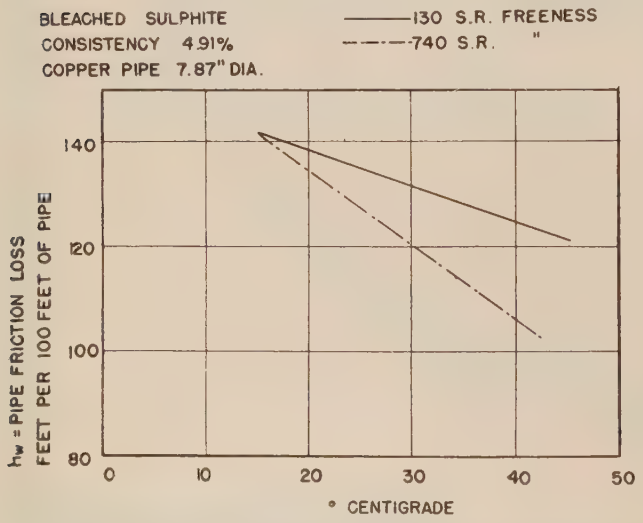


*Fig. 20. Change in pipe friction loss with temperature*

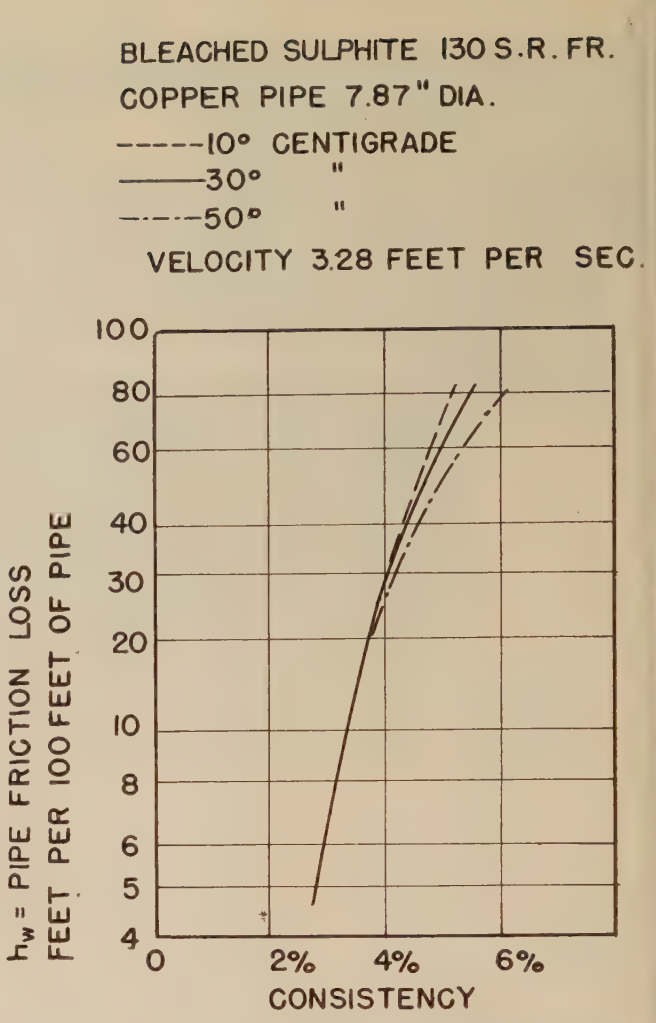


*Fig. 21. Friction loss vs. consistency for various temperatures*

In the following test group the content of fibrous material remained constant at 3.0%, while the specific clay content was increased from test series to test series. Table IV gives the computation figures for the different specific clay contents, the friction losses of the filler-free suspension being compared with those of the filler-containing suspension.

Average computation values derived from the average values of the individual pipes are:

For a clay content of 18.0%: $h_w'/h_w - 0.885$
For a clay content of 26.5%: $h_w''/h_w - 0.835$
For a clay content of 32.2%: $h_w'''/h_w - 0.785$

It will be noted that the computation values are substantially unaffected by the velocity or the pipe diameter. The addition of clay results in a reduction of the friction loss of the suspension. If the computation values are plotted against the clay content (Fig. 26), a straight line is obtained. Thus the friction loss is proportionately reduced in the lower regions with an increasing clay content. Considering the total consistency of the suspensions, it has been found that in

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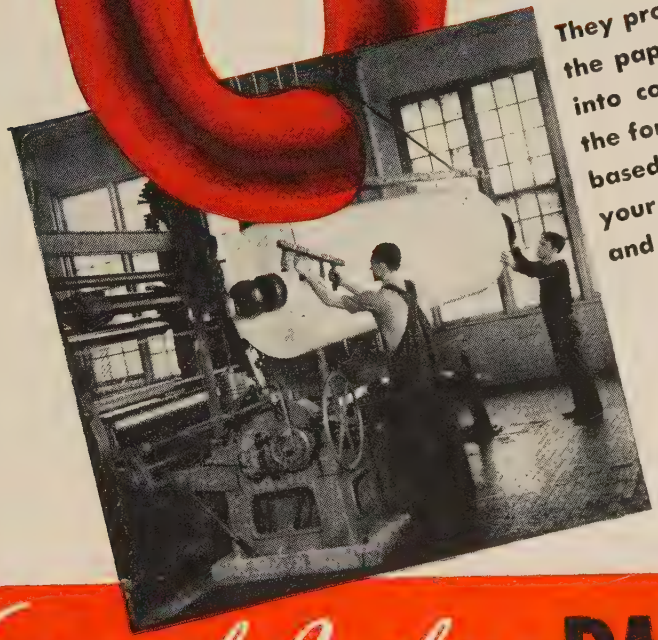

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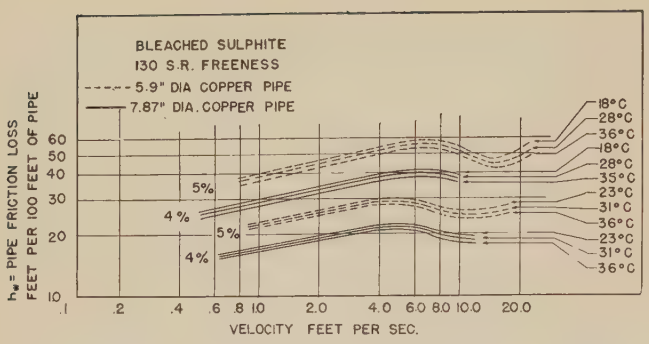



*Fig. 22. Friction loss vs. velocity for various temperatures, consistencies, and pipe diameters*

spite of an increase in consistency the friction losses are reduced.

As a result of the tests made with clay suspensions it can be said that the addition of clay to water increases the pipe friction but that the addition of clay to pulp results in a decrease of friction losses, a phenomenon which becomes more pronounced in its practical application as the filler content is increased.

**Table IV**

| *Velocity, ft./sec.* | *3.28* | *9.84* | *16.40* | *22.96* | *Average* |
|---|---|---|---|---|---|
| | | Pipe—5.90-in. Cast iron | | | |
| $h_w$—Clay-free groundwood | 22.75 | 28.6 | 30.5 | 32.6 | |
| $h_w$—18.0% Clay | 20.5 | 25.3 | 26.7 | 29.0 | |
| Computation value | 0.9 | 0.985 | 0.875 | 0.89 | 0.89 |
| $h_w$—26.5% Clay | 19.25 | 23.95 | 25.25 | 27.5 | |
| Computation value | 0.845 | 0.835 | 0.83 | 0.845 | 0.84 |
| $h_w$—33.2% Clay | 17.75 | 22.5 | 23.75 | 25.8 | |
| Computation value | 0.78 | 0.785 | 0.78 | 0.79 | 0.785 |
| | | Pipe—5.90-in. Copper | | | |
| $h_w$—Clay-free groundwood | 17.7 | 16.2 | 18.8 | 21.5 | |
| $h_w$—18.0% Clay | 15.7 | 14.85 | 17.05 | 19.8 | |
| Computation value | 0.885 | 0.915 | 0.905 | 0.92 | 0.905 |
| $h_w$—26.5% Clay | 14.75 | 13.95 | 16.2 | 18.95 | |
| Computation value | 0.835 | 0.86 | 0.865 | 0.88 | 0.86 |
| $h_w$—32.2% Clay | 14.1 | 13.4 | 15.6 | 18.3 | |
| Computation value | 0.795 | 0.825 | 0.83 | 0.85 | 0.825 |
| *Velocity, ft./sec.* | *3.28* | *6.56* | *9.84* | *13.12* | *Average* |
| | | Pipe—7.87-in. Cast iron | | | |
| $h_w$—Clay-free groundwood | 15.8 | 17.3 | 17.2 | 16.45 | |
| $h_w$—18.0% Clay | 13.8 | 15.0 | 15.0 | 14.65 | |
| Computation value | 0.875 | 0.865 | 0.875 | 0.89 | 0.875 |
| $h_w$—26.5% Clay | 13.1 | 14.2 | 14.1 | 13.6 | |
| Computation value | 0.83 | 0.82 | 0.82 | 0.825 | 0.825 |
| $h_w$—33.2% Clay | 12.45 | 13.2 | 13.05 | 12.6 | |
| Computation value | 0.79 | 0.765 | 0.75 | 0.765 | 0.77 |
| | | Pipe—7.87-in. Copper | | | |
| $h_w$—Clay-free groundwood | 12.0 | 11.2 | 10.2 | 9.8 | |
| $h_w$—18.0% Clay | 10.5 | 9.8 | 9.05 | 8.8 | |
| Computation value | 0.875 | 0.875 | 0.888 | 0.90 | 0.885 |
| $h_w$—26.5% Clay | 10.05 | 9.4 | 8.6 | 8.4 | |
| Computation value | 0.84 | 0.84 | 0.84 | 0.86 | 0.845 |
| $h_w$—33.2% Clay | 9.4 | 8.8 | 8.1 | 7.8 | |
| Computation value | 0.785 | 0.785 | 0.795 | 0.795 | 0.79 |
| *Velocity, ft./sec.* | *1.64* | *5.10* | *6.56* | *9.02* | *Average* |
| | | Pipe—9.84-in. Cast Iron | | | |
| $h_w$—Clay-free groundwood | 11.45 | 14.0 | 14.5 | 12.8 | |
| $h_w$—18.0% Clay | 10.0 | 12.3 | 12.6 | 11.2 | |
| Computation value | 0.875 | 0.88 | 0.87 | 0.875 | 0.875 |
| $h_w$—26.5—Clay | 9.5 | 11.55 | 11.5 | 10.05 | |
| Computation value | 0.83 | 0.825 | 0.795 | 0.785 | 0.81 |
| $h_w$—33.2% Clay | 8.9 | 10.85 | 10.8 | 9.4 | |
| Computation value | 0.775 | 0.775 | 0.745 | 0.735 | 0.76 |

## SUMMARY


The value of the present day knowledge of pipe friction losses for water has been pointed out in the introduction. The occasion for this present work arises from the fact that the knowledge of pipe friction loss, as it occurs in pulp suspensions, has not been entirely satisfactory up to the present time. The few experimental investigations which have been published in this field have almost always defined only the relationship between pipe loss, consistency, and velocity. These relationships have been defined only in general terms and only for one or two pulps which have not been sufficiently identified as to their condition of treatment. Moreover the results of investigators show considerable differences which do not lend themselves to any interpretation, as sufficient data are lacking as to the kind of experimental layout which was used, as to the accuracy of the measurements which were obtained, and above all as to the condition of the stock used in the majority of cases.

In the present work the influence of pulp consistency and velocity on pipe friction loss was established with a carefully constructed experimental layout which allowed an accuracy of measurement sufficient in all ranges within which measurements could be taken and at the same time sufficiently defined in detail for seven different pulps (unbleached and bleached sulphite, unbleached kraft, bleached straw, unbleached straw, groundwood, and steamed groundwood). The measurements cover a consistency range of 0 to 5.0% and a velocity range of 1.64 to 32.8 feet per second.

Figure 27 shows a comparison of the observed dependence of friction loss on the velocity with the results of other investigators for a pulp consistency of 2.5% and a cast pipe of 5.90-inch diameter. In this figure it is to be noticed that the curves of Forrest and Grierson (*2*) and our curves are determined on unbleached sulphite pulp, while the curve of Trimbey (*1*) applies to sulphite pulp and groundwood as Trimbey has found no difference in friction loss for the two pulps. The curve of Haussner (*7*) is calculated according to the equation established by him for the friction loss of pulp.

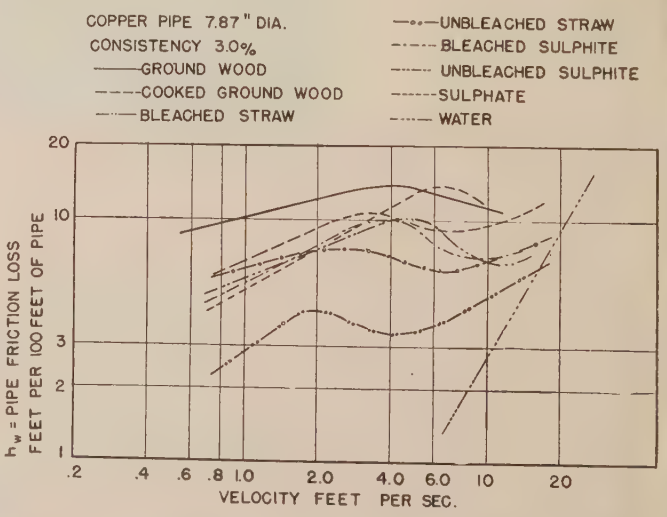
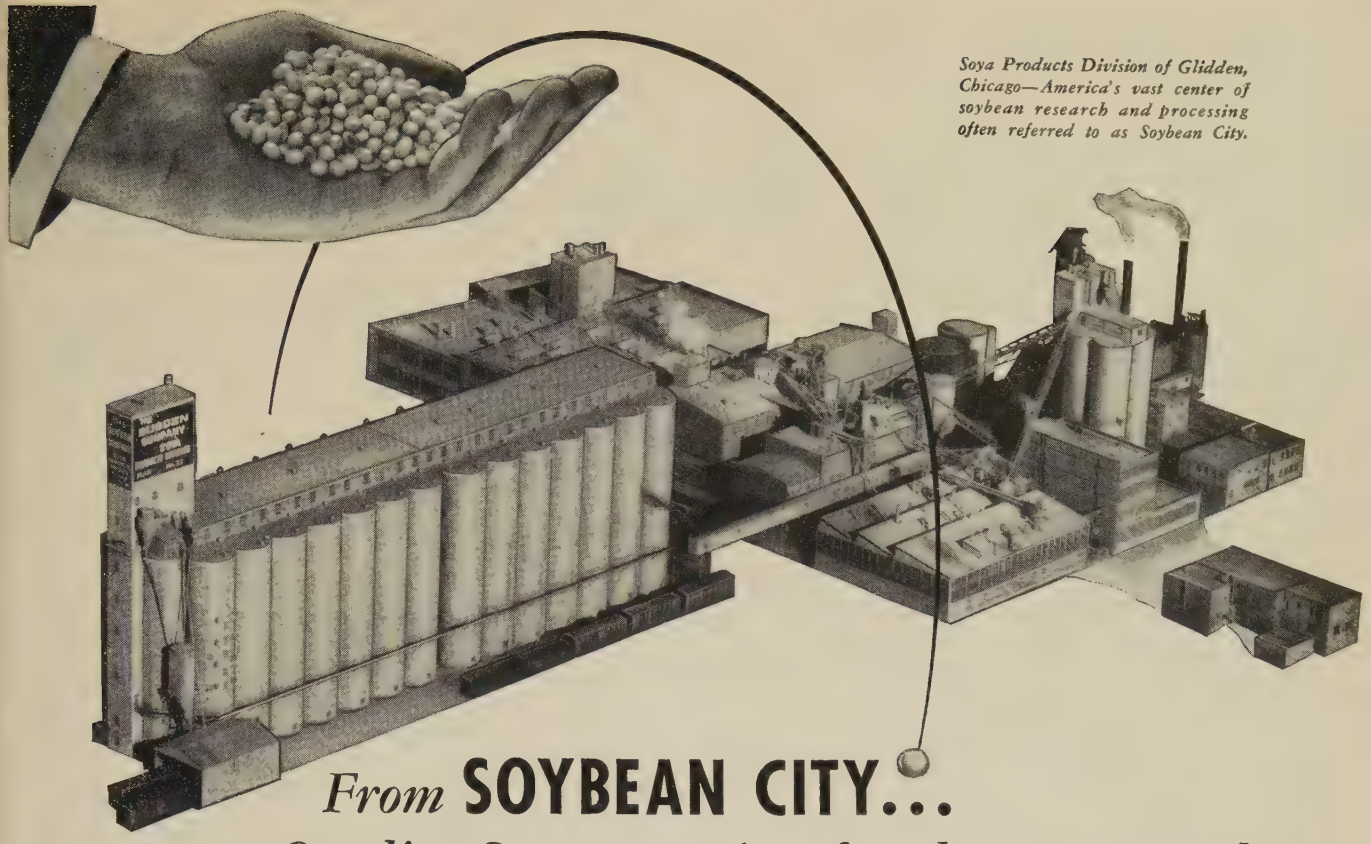




*Fig. 23. Friction loss vs. velocity for various pulps*



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Essentially the curves of Forrest and Grierson agree with those of ours; both show a maximum (point) after the first rise of the friction loss with the velocity, show a drop of friction loss to a minimum, and in the case of further increase in velocity show a strong rise in the loss value. The curve of Forrest and Grierson differs, however, from that found by us by the fact that the maximum first occurs at a greater velocity and in that it also reaches a higher value. After crossing the minimum, both curves approach each other until they coincide. A comparison of the pipe roughness in terms of the results with water shows that the roughness of the pipe used by us was only slightly less than the roughness of the pipe used by Forrest and Grierson. An explanation for the different behavior is not possible without further consideration; perhaps it lays in a different degree of cooking of the pulp used.

Singularly Forrest and Grierson find for groundwood a friction loss curve without maxima or minima in contrast to the results of this work where maxima and minima in the case of groundwood are apparent although less distinct than in sulphite pulp.

Forrest and Grierson have attempted to give an explanation for the peculiar shape of the curve which they have found. This explanation, however, lacks an experimental basis. They have assumed different kinds of turbulence for the liquid flow and for a curve shape at different velocities have given some pictures of flow assumed by them for flow of water, groundwood, and sulphite pulp. The pressure measurements carried out in the present work, however, permit no confirmation for the velocity gradient surmised by Forrest and Grierson in the flow of sulphite pulps in the case of the velocities in question. Also the velocity gradient assumed for water does not agree entirely with the form of the velocity gradient known for turbulent flow in pipe (*30*). As the measurements of the concentration distribution over the pipe cross section also presented no useful result, the explanation of this phenomenon must remain reserved for further work.

In agreement with Brautlecht and Sethi (*5*) and Schmidt-Nielsen (*12*), Forrest and Grierson have also found that the friction loss of highly diluted fiber suspensions is less than that of water. On the basis of this work this can be amplified to the point that at high velocities the friction loss of higher consistencies also is less than the friction loss of water, and at a greater velocity the suspension in question possesses a higher concentration. Forrest and Grierson and Schmidt-Nielsen explain these phenomena by the fact that in the case of fiber suspensions the turbulent flow is not as strong as in the case of water. The corrections of this assumption is, of course, not confirmed absolutely but appears credible.

As can be seen from Fig. 27, the curve found by Trimbey (*1*) is similar up to a velocity of about 4.92 feet per second to that of Forrest and Grierson but deviates fundamentally with increasing velocity. While the curve of Forrest and Grierson has a turning point, that of Trimbey increases constantly. As nothing is known about the way Trimbey's experiments were carried out and about the accuracy of the measurements obtained and as Trimbey has found, in contrast to almost all other writers, the same friction loss for groundwood and sulphite, one can only surmise that his accuracy of measurement has not been very great. Klossen (*8*), Peirce (*11*), and Voith (*17*) have observed similar curve courses as Trimbey. Also in these works none of the authors gives an exact account of the pulp used in the reported experiments. Likewise, state

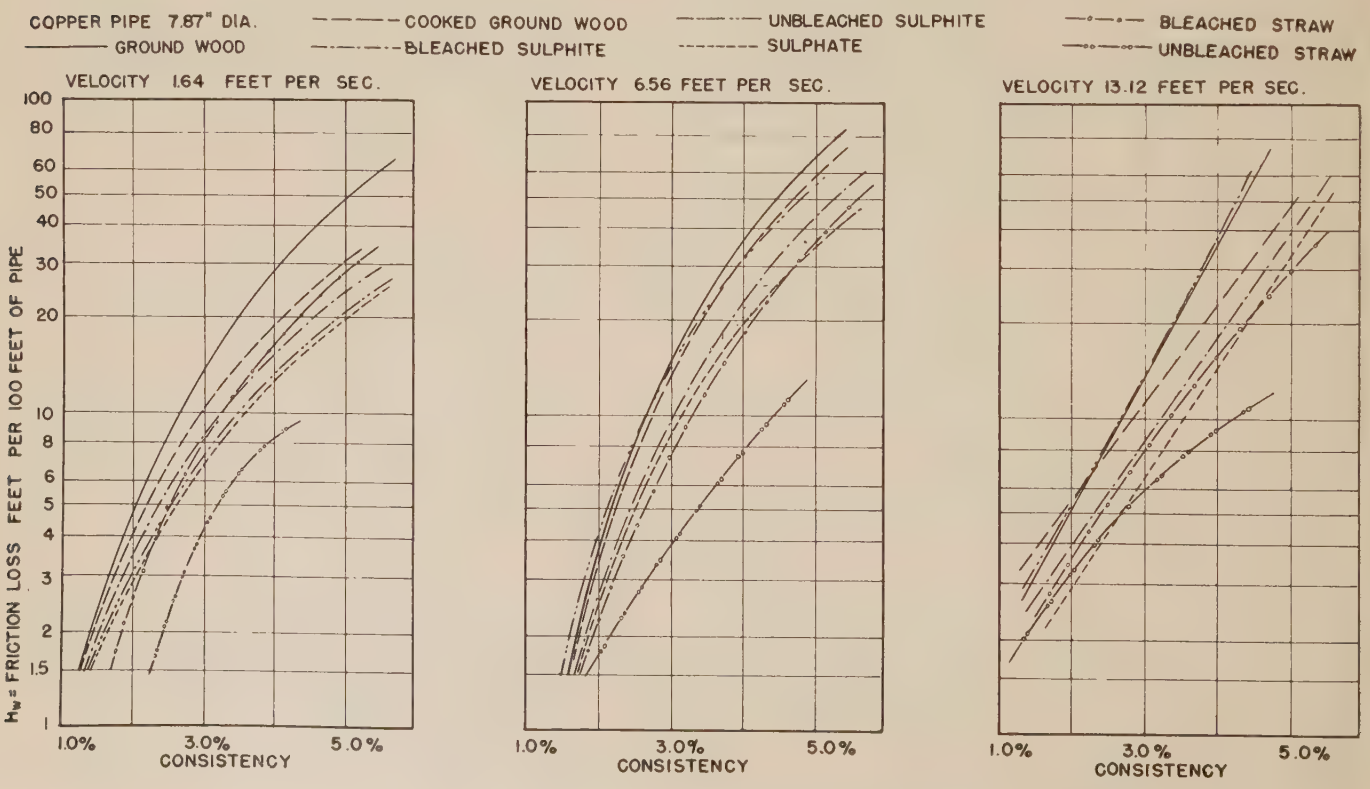


*Fig. 24. Consistency vs. friction loss for different pulps at different velocities*

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ments as to the experimental layout and as to the accuracy of the measurements obtained are not available; only Peirce reports a pressure measurement arrangement with which he has carried out a part of his experiments.

Already the results of earlier works have shown clearly that for fiber suspensions the friction laws (*31*) valid for water do not hold true. This also holds good for dilute suspensions on which Brautlecht and Sethi (*5*) have carried out their experiments and calculations. The outline in Fig. 27 which does not express the peculiarity of the friction loss curve for stock suspensions, and which was calculated according to Haussner's formula (*7*), shows that formulas which are derived from friction laws give completely erroneous results.

Similar to earlier works the increasing effect of pulp consistency on friction loss is shown clearly in the experimental data. It is noticed, of course, that under certain conditions the pulp consistency can also exert the opposite influence since at certain velocities it reduces the friction loss of fiber suspensions below that of water.

The influence of pipe diameter on the friction loss of pulp suspensions can be worked out clearly on the smooth copper pipes, investigated here for the first time, by the use of four different diameters. Here a similar relationship exists between water and fiber suspensions. It is noticed from this investigation that in the measurements on rough pipe the influence of diameter on the pressure drop cannot be established with sufficient certainty since the different roughness of pipe causes disturbances. For the first time the work with smooth pipes which differ only with respect to roughness creates an unobjectionable basis for the experiments.

The use of rough and smooth pipes of the same diameters allows the importance of the degree of roughness to be determined. The investigation of the influence of the degree of roughness almost always shows for the rough pipes a higher friction loss than for the smooth. The difference is dependent as much on the velocity as on the pulp consistency, and deviates essentially from that of water. The assertion made by Haussner (*7*) that in the case of high-pulp consistencies the influence of pipe roughness disappears, is disproved by the present work.

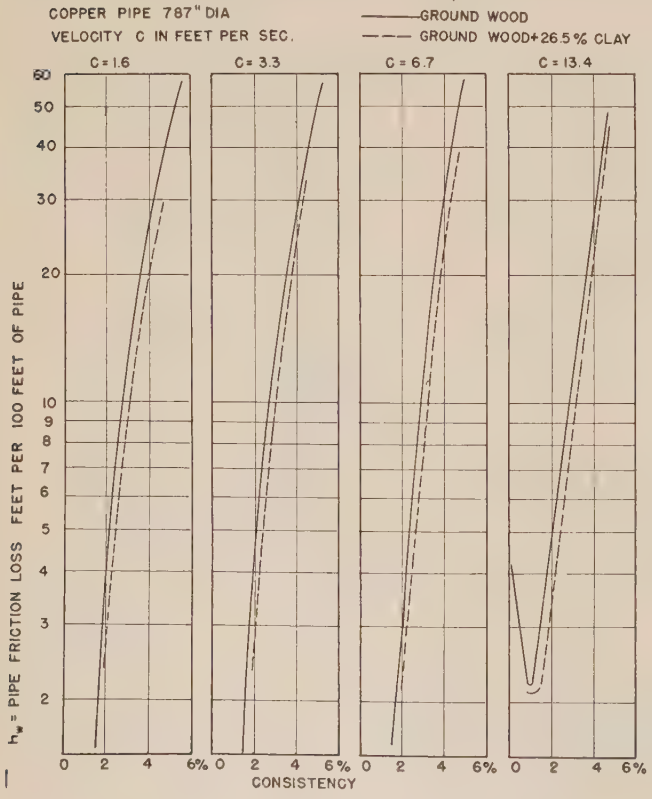


*Fig. 25. Pipe friction loss for pure and loaded groundwood*

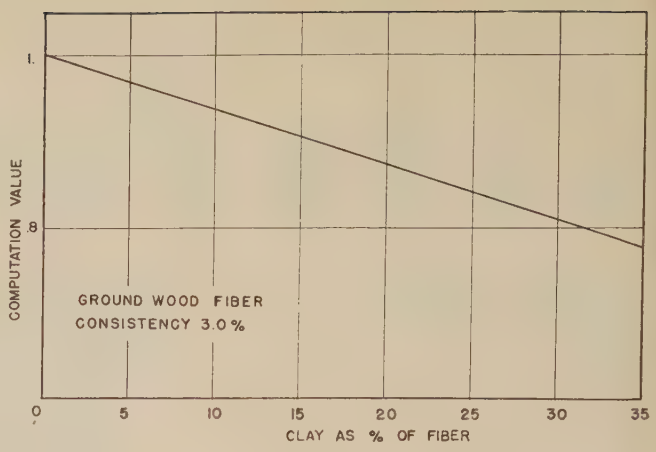


*Fig. 26. Computation value vs. clay content*

Although in the experiments for establishing the influence of average fiber length the difference in the average fiber length was very considerable, it affected the friction loss of the suspension very slightly. In the ranges of velocity and concentration investigated, pulp with the higher average fiber length shows a somewhat higher friction loss.

The investigations which should clarify the influence of freeness on the friction loss and which have been carried out on three different pulps show no uniform results. The friction losses reported after the different beatings for the individual pulps, show that the freeness in each pulp works out differently without permitting a definite relationship between friction loss and freeness to be recognized, except in the case of the pulps investigated. Since the measured results of a series of yet undetermined pulp properties are affected in the testing of freeness, this conclusion is not very surprising. Anyhow it may be accepted as proved that the pulp freeness determined by Schopper-Riegler test is a factor affecting friction loss so that the view expressed by Baker (*28*), according to which measurements of friction loss only lead to useful results if a change in freeness is avoided during measuring, has our support.

The experiments which show the relationship of friction loss to temperature, prove in the region investigated, a linear decrease of friction loss with increasing temperature. This is practically independent of pipe diameter and velocity of flow. On the other hand, it is influenced by the freeness in such a way that in the case of free pulp at the same pulp consistencies the friction loss of the suspension decreases more rapidly than in slow pulps. Likewise pulp consistency has a strong influence; with increasing pulp consistency the effect of temperature on the friction loss increases quite considerably.

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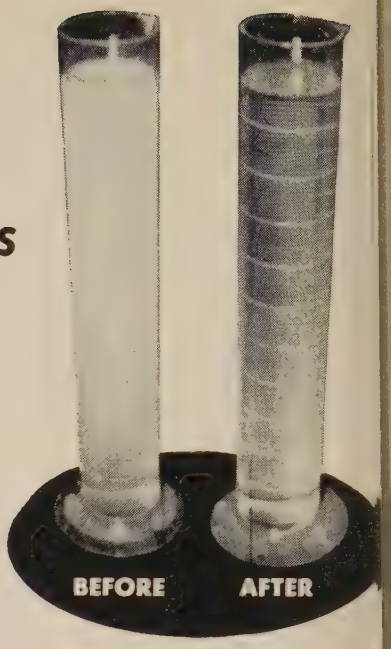


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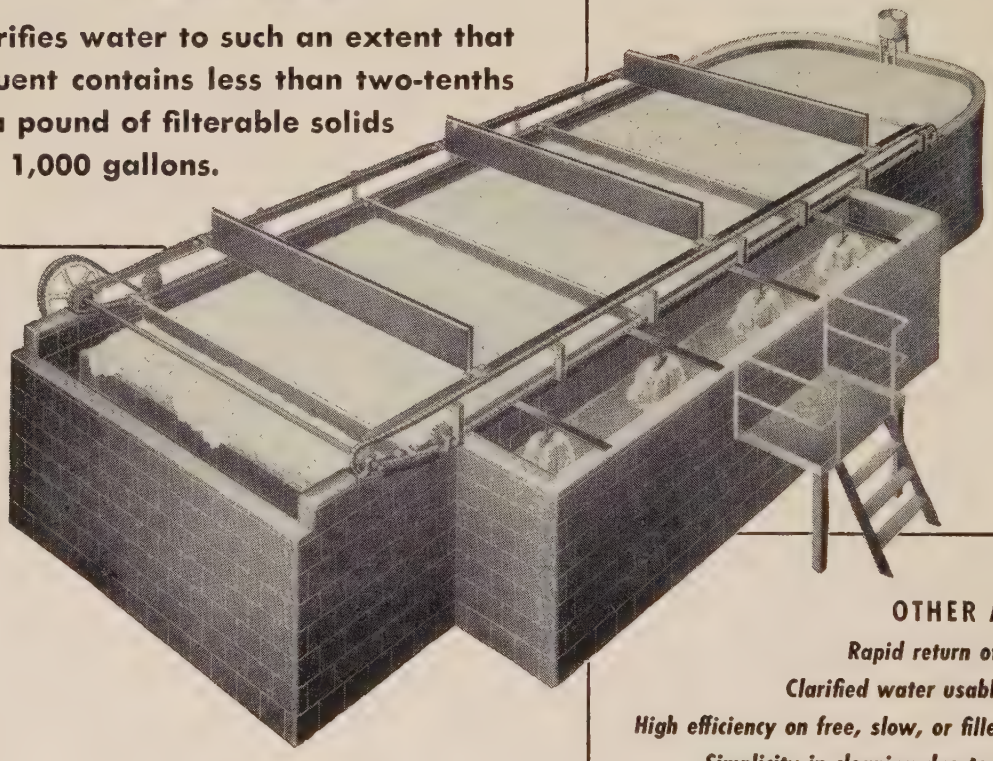

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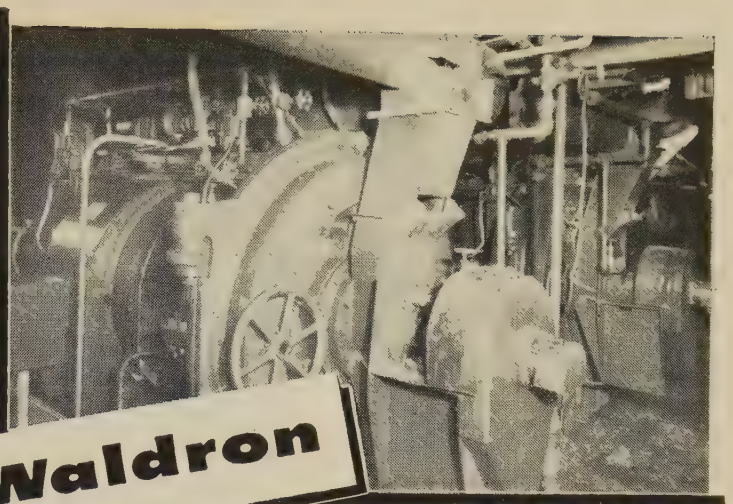

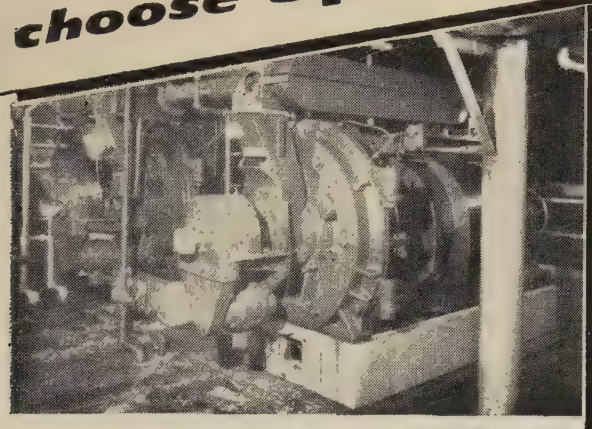

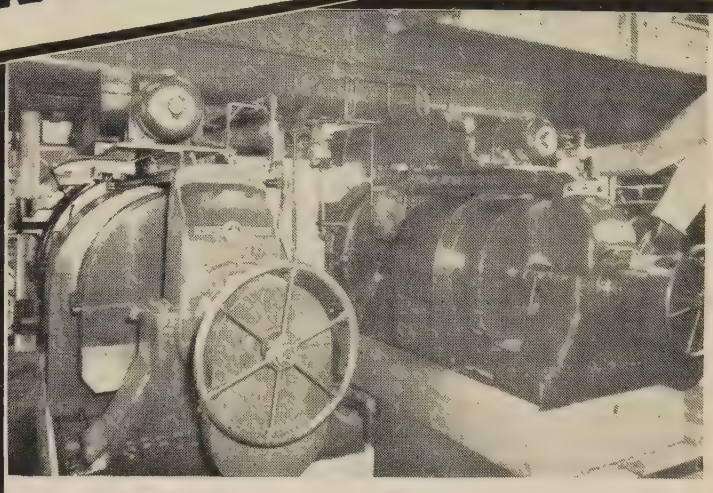

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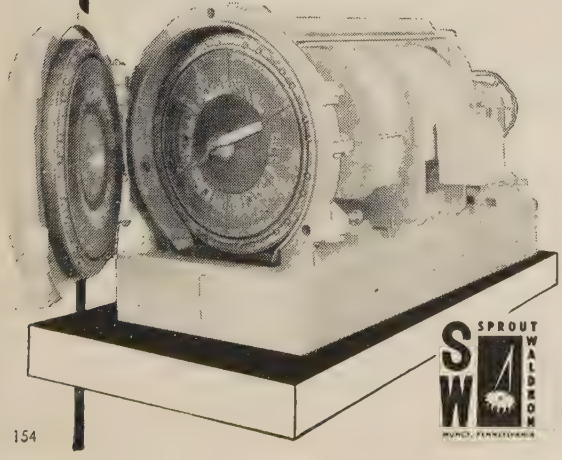


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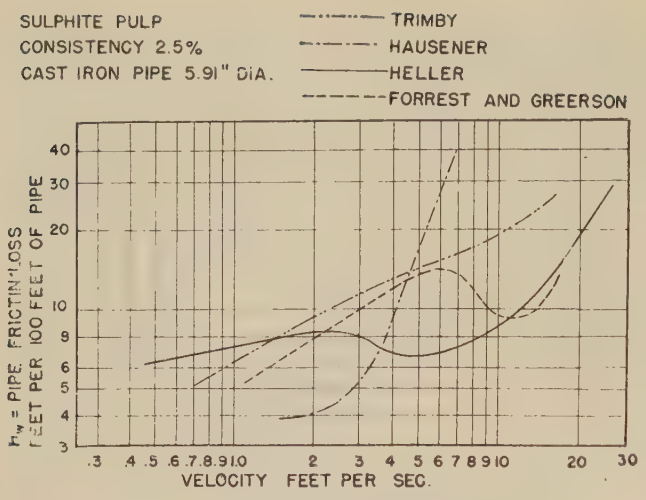


*Fig. 27. Comparison of friction-loss curves by different investigators*

The measurements of friction losses of different kinds of pulp furnish an explanation why the experimental results of individual authors so seldom agree. The friction loss curves of the individual pulps show in the friction loss-velocity diagram a similar course throughout; they differ only by their different positions in the coordinate system. It is to be assumed that the differences in friction loss under otherwise similar conditions not only are caused by the nature of the individual pulps, but also that they arise within a certain pulp, caused not only by different freenesses but also by the physical structure of the fiber, its elasticity, and its ability to remain in suspension. An explanation of the peculiar behavior of individual pulps will only be possible when the knowledge of the nature of fibers in the suspended state has been expanded.

As far as the addition of fillers is concerned, it works out differently for water than for a fiber suspension. While the friction loss of water shows a slight increase with clay, the clay addition to a fiber suspension causes a friction decrease, a fact which has already been reported by Bond (*4*) and Peirce (*11*). In both cases the shape of the friction loss curve is not disturbed; it is only displaced. Likewise the velocity exerts no special influence. At equal pulp consistencies the friction loss decreases linearly with increasing clay content.

The present investigations for the measurement of friction losses of pulp suspensions remain limited to straight lengths of pipe and the establishment of the different influences affecting this friction loss also remains limited. Likewise experimental efforts have failed to give an explanation to the results which have been found, as the establishment of the most economical demand of pulp consistency and pipe velocity fails due to the lack of a reliable and controllable mathematical relationship between pipe loss, velocity, pulp consistency, and pipe diameter and to the lack of accurately known pump efficiency. Nevertheless, the results of this work may be adapted for suggesting useful material to the working engineer in the planning of pump layouts This material previously has not been available.

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The tests on which this report is based were conducted in the pump testing room of the J. M. Voith Shops in Heidenheim. We feel very much indebted to Hermann Voith and Hans Voith for their kind offer of the testing facilities.

The unabridged report was submitted by one of us (Heller) as his thesis to the Technische Hochschule, Darmstadt.

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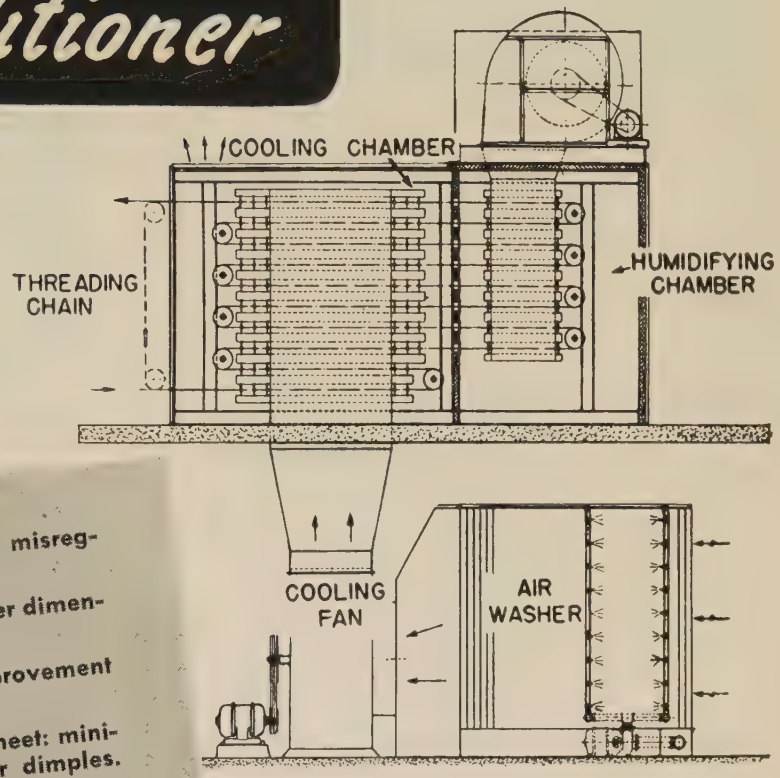


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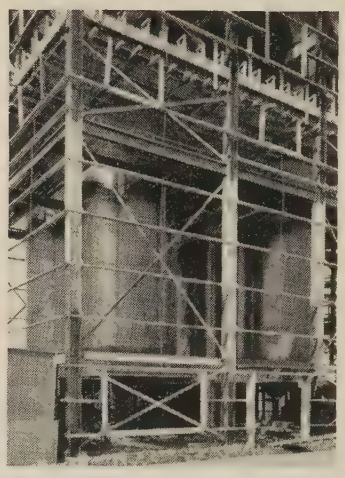

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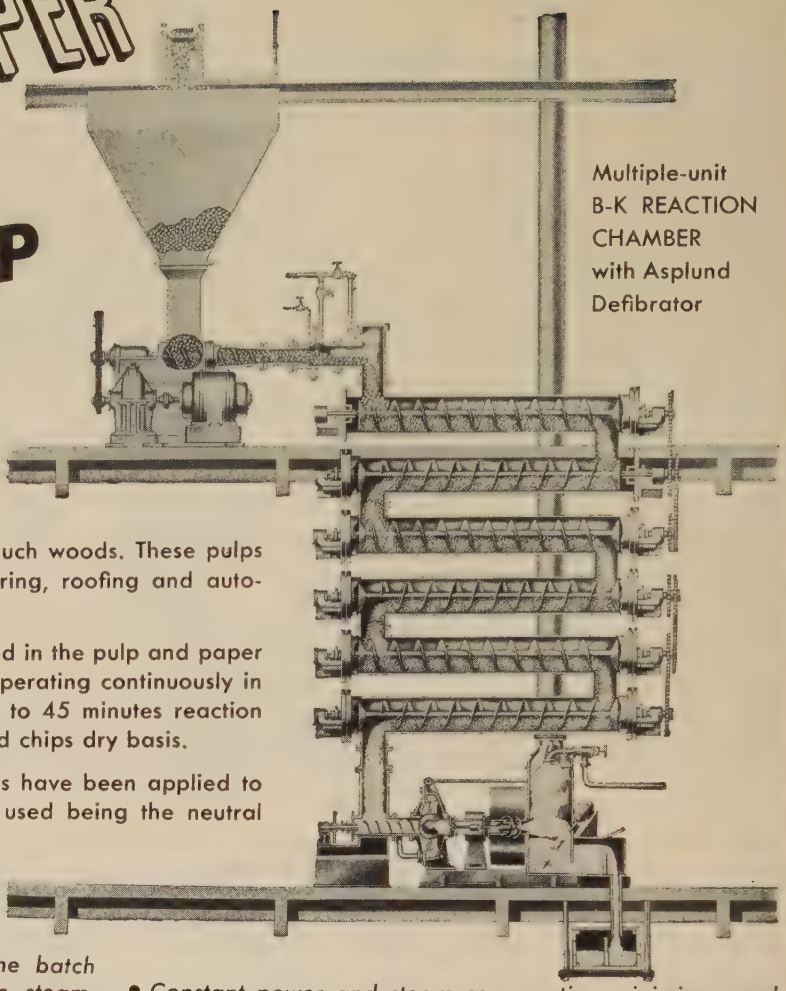

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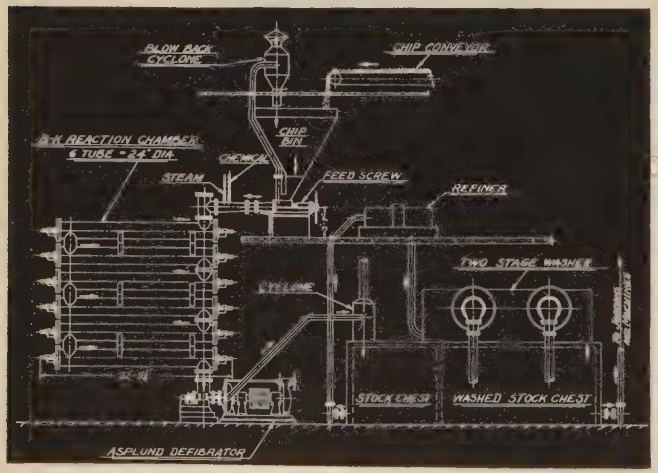
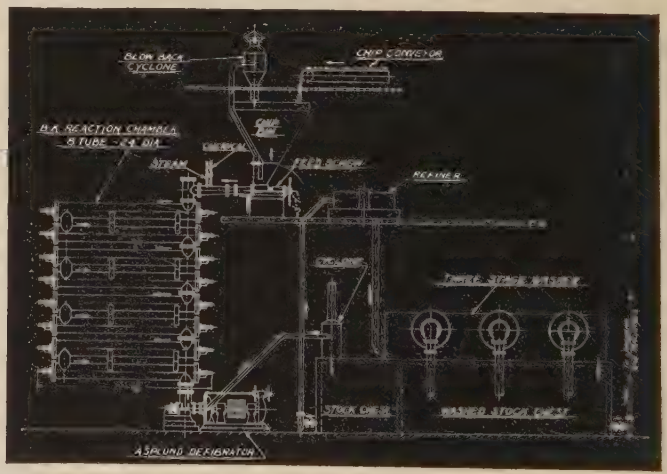



Flow drawing of the CHEMIPULPER with auxiliary equipment for producing semi-chemical pulps for Corrugating Board.




Flow drawing of the CHEMIPULPER with auxiliary equipment for producing semi-chemical Neutral Sulphite and Kraft Pulps.

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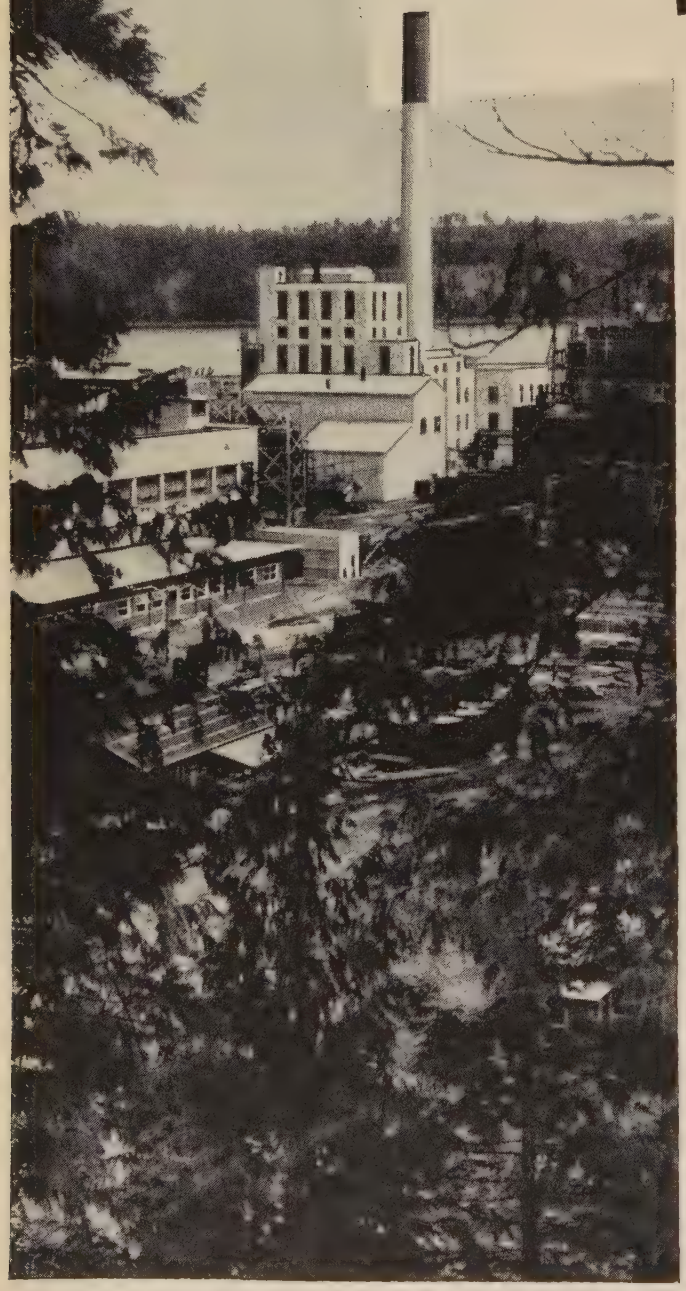

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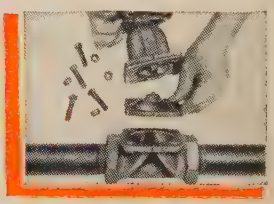

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# The Measurement and Significance of Swelling of Cellulose Fibers

WILFRED GALLAY

**Methods of measurement of the swelling of cellulose fibers in water are reviewed and the results compared in a general way. Swelling of cellulose in water is related to swelling of high polymers in general, and factors affecting such swelling are considered. The significance of swelling of cellulose fibers in pulp preparation and paper properties is discussed. The need for further research on methods of measurement of the swelling of cellulose fibers is emphasized.**

POLYMERS OF high molecular weight, in contrast to low molecular weight materials, possess the ability to swell in certain suitable liquids. Swelling involves the imbibition of liquid with accompanying enlargement of volume; the degree of swelling may range from the very small to infinite swelling—i.e., from complete dispersion to a sol. Such liquid take-up should be distinguished from mere capillary imbibition, where liquid is taken up in available channels without alteration in the dimensions of the solid or change in cohesion and physical properties.

The generalized concept of the configuration of a linear polymer is now reasonably well established as a coiled-up form, the encompassing volume of which depends on the freedom of rotation of the primary valence linkages and, to some extent, also on spatial considerations of rings and substituent groups, as well as intramolecular attractions among polar groups on portions of the molecule. This is a dynamic picture in view of continual changes of configuration brought about by kinetic energy. Superimposed on this picture, and modifying it to a greater or lesser extent, are the forces of intermolecular attraction of varying magnitude, which might be grouped under the term secondary valencies. These range in magnitude with the polarity and number of the groupings partaking in the intermolecular attraction. In the case of a polymeric aliphatic hydrocarbon, for example, such intermolecular attraction would be expected to be very small and, indeed, the physical properties of such materials bear out this expectation—e.g., high softness and flexibility. With the introduction of a benzene ring substituent into the monomer, as in polystyrene, the material becomes relatively inflexible and brittle as a result of loss of freedom of motion. The addition of a compatible low molecular weight liquid to such a polymer results in swelling with increasing softness. The cohesion among molecules is weakened and no polar groupings are available to resist slippage among the molecules. Thus, there is no addition agent, or plasticizer, known today for polystyrene which will confer a substantial degree of elasticity to the polymer. Where a relatively polar substituent is present in the monomer—e.g., chlorine or acetate—the polymer is relatively brittle and hard, but many plasticizers are available which are effective in decreasing molecular cohesion but which also leave sufficient intermolecular points of anchorage to give flexibility or softness together with a high degree of elasticity. The function of a plasticizer is essentially that of effecting a decrease in molecular cohesion by the neutralization of polar groups and thus releasing segments of the molecules to greater freedom of motion. Varying degrees of plasticity and elasticity may thus be attained.

There would appear to be no reason why cellulose should not be considered as an example of a type of linear polymer from this general point of view. As a result of the large number of substituent polar hydroxyl groups, cellulose possesses a high degree of molecular cohesion, and the resulting rigidity is probably further enhanced by the ring structure. In such a polymer, alignment of a large proportion of polymer segments may be expected and, thus, cellulose is relatively highly crystalline.

The possibility of plasticizing cellulose in order to enhance the plasticity and flexibility, and to decrease brittleness, is obviously important from the point of view of papermaking. Unfortunately, no nonfugitive plasticizers are available for cellulose and, indeed, water (including aqueous solutions) is the one medium which comes practically into consideration. The swelling of cellulose fibers by water, therefore, is a question of fundamental importance in dealing with the manufacture of paper, and the relationship between the extent of such swelling and the properties of the paper made from these fibers is of great interest from the fundamental point of view and may be of great significance in practical papermaking.

There is given below a brief review of the methods heretofore used for the measurement of the swelling of pulp and other cellulose fibers, with accompanying examples of pertinent data obtained.

## DIRECT MICROSCOPIC MEASUREMENT

The determination of the swelling of pulp and cotton fibers and, also, of regenerated cellulose fibers, by direct measurement microscopically, has been carried out by a number of workers. The change in the diameter of fibers resulting from swelling has been measured by observation of both the whole fiber from the side or by examination of cross sections. The change of length of the fibers during swelling is only a fraction of 1% (*1*) and is very difficult to measure with a good degree of precision. Weidner (*2*) has shown an increase of 10% in width for sulphite fibers with an increase from 0 to 95% in relative humidity. Heuser and Bartunek (*3*) showed that cotton fibers swelled to a

WILFRED GALLAY, Research Consultant, E. B. Eddy Co., Hull, P. Q., Canaad.

maximum in about 15% sodium hydroxide and, in this swelling agent, the increase in volume calculated from diameter changes was found to be about 78%. Clayton and Peirce (*4*) found with cotton fibers an increase of about 15% in diameter in going from the dry state to saturation with water vapor. This corresponds to a volume increase of about 34% and a weight increase of about 22%. It has been stated (*5*) that dry papermaking fibers increase in diameter about 20% when fully saturated with water. Preston and Nimkar (*6*) have reviewed critically this direct method of measurement of swelling and have emphasized the difficulties inherent in the method, together with striking examples of the gross inconsistencies which have arisen as a result of such measurements. It would appear that this direct method shows little promise for the purpose.

### PARTIAL EXTRACTION

This method, developed by Ebert (*7*) and later used by Jayme and Froundjian (*8*), consists of the addition of moist pulp to dry dioxane and subsequent measurement of the dielectric constant of the dioxane together with extracted water. An equilibrium is attained for each individual system and it is assumed that this equilibrium represents an extraction of the free water by the dioxane, leaving the water of swelling in the fibers. It is noted, however, that the equilibrium is not absolute and that the apparent swelling of the cellulose increases with increase in the dielectric constant of the dioxane after extraction. Attempts were made, therefore, to conduct these measurements in such a way as to maintain a constant final dielectric constant by varying the proportion of dioxane available. It would seem to be apparent that the dioxane must effect a partial deswelling of the cellulose, similar to that of any solvent miscible with water, and that the water involved in swelling cannot be defined by this method as distinct from free surface water.

### DILATOMETRIC SWELLING

The classical method of Posnjak (*9*), involving the direct measurement of volume increase of a polymer in contact with a swelling medium by displacement of mercury, has been applied to cellulose by several workers with results of considerable interest. Lottermoser and Radestock (*10*) showed, by this method, that cellulose possesses a maximum swelling in sodium hydroxide solution of 11.19% by weight, which agrees quite well with data obtained by other methods.

Kress and Bialkowsky (*11*) carried out measurements of the swelling of sulphite pulp in a number of liquids, and showed clearly the relationship between swelling and properties of paper made from pulp suspended in such media. The data included the following:

| *Liquid* | *Increase in volume, %* |
|---|---|
| Water | 90 |
| Methyl alcohol | 62 |
| Ethyl alcohol | 40 |
| Propyl alcohol | 6 |
| Butyl alcohol | 4 |
| Fuel oil | 2 |
| Nitrobenzene | 17 |

The influence of the polarity of the liquids used is clearly seen, and these workers noted the close relationship between swelling on the one hand and beating and paper properties on the other.

Young and Rowland (*12*) also used the dilatometric method in a study of the swelling of a variety of chemical and mechanical pulps. The increase in volume in the different pulps as a result of swelling in water ranged from about 40% to 100%. The determination of pentosan content of these pulps showed a definite relationship of increased swelling power with increase in the hemicellulose content. In view of other data relating hemicellulose content, ease of beating, and strength, it would appear that degree of swelling is a primary factor in these interrelationships.

The dilatometric method was used on pulp pads compressed to a density of about 1.0 in both of these researches and, hence, the data may be expressed on either a weight or volume basis without change. In all cases, air-dried pulp was used.

### CENTRIFUGE METHOD

The centrifuge method involves the use of a standard centrifuging procedure on a suspension of pulp in the liquid under consideration, followed by weighing the centrifuged pulp, drying, and weighing again. Following the preliminary use of this method by Hubert, Mathes, and Weisbrod (*13*), Jayme has developed this procedure further and applied it in several researches (*14–17*).

The method depends on the concept of the ability to produce by centrifuging a reasonably clear definition between the water involved in swelling and the free water on and between the fiber surfaces. It is stated that the amount of free water remaining after the centrifuging procedure depends on such morphological factors as the fiber length and thickness, the diameter of the lumen, the thickness of the fiber wall, and the shape of the fiber. The general conclusion is reached that, under standard conditions of centrifuging and for morphologically similar fibers, the error produced by the retention of free water is constant (*15*). It has been estimated elsewhere (*6*) that about 9% of water may be retained in such interfiber spaces and, furthermore, that it is possible that the centrifuging may exert sufficient force to deform the fiber with accompanying extrusion of imbibed water.

The application of the centrifuge method of swelling determination to beaten fibers requires special consideration. The volume of small channels and spaces developed in a mass of beaten fibers will undoubtedly increase the retention of free water under the same centrifuging conditions and, thus, it may be expected that this error in the determination will increase with the extent of beating.

The data given by Jayme and his co-workers (*14*) show a range of about 65 to 90% increase in weight for a number of chemical pulps in air-dry condition upon swelling in water. Using a variety of pulps, swelling in various concentrations of sodium hydroxide shows maxima ranging from 260 to 350% increase in weight; with all pulps, maxima are obtained at a concentration of 10.5% sodium hydroxide. It is noted that these maximum swelling values in alkali are in the same order as the hemicellulose content of the pulps measured. Swelling determinations carried out on wet pulps, not

previously dried, showed results ranging from about 140 to 190% increase in weight. Progressively greater degrees of drying resulted in further decreases in swelling. Beating resulted in a large increase in swelling—e.g., from 187% for unbeaten pulp to 287% for pulp beaten 40 minutes. Salts of monovalent and divalent cations had little effect on swelling, but minute traces of alum effected an appreciable reduction in swelling. A precision of ± 1.2% is claimed in this work.

Swelling data on a variety of cellulose fibers, including varying bleaching and refining procedures, show increased swelling with higher hemicellulose contents, and increased swelling with decreased lignin content. Thus, a very hard unbleached sulphite was found to show much greater swelling than an ordinary unbleached sulphite (*18*). No direct relationship could be found between degree of swelling and freeness. Swelling was shown to have a hysteresis effect (*15*), in that fibers subjected to swelling at lower temperatures retain higher swelling values in later equilibrium at higher temperatures.

Renaud (*19*) has also reported swelling data obtained by a slightly modified centrifuge method. With a dried bleached sulphite, a value of 78% increase in weight was obtained in the unbeaten state, which is of the same order as the data of Jayme and co-workers quoted above. Beating for 11 hours produced a maximum swelling value of 347%. With dried bleached straw pulp, the unbeaten swelling value of 120% increased to a value of 742% after 22 hours of beating. With cotton linters, the unbeaten swelling value of 68% increased to a maximum of 163% after 25 hours of beating. In view of the very excessive beating action in these experiments, it would appear that retention of water on centrifuging might show sharp increases, and that the swelling values following the lengthy beating periods are probably unduly high for this reason. No relationship was found in this work between swelling value and freeness.

## PERMEABILITY

In a recent study of the specific surface of cellulose fibers by the liquid permeability method, Robertson and Mason (*20*) introduced a modification of the Kozeny-Carman equation as a result of which the specific surface area and the effective specific volume were determined simultaneously. In this work, the permeability coefficient of a pad of fibers was measured as a function of the pad concentration, and the mass concentration was altered to a dimensionless "filled-volume fraction" by multiplying by a factor representing the effective volume of the swollen fibers. This effective specific volume in cubic centimeters per gram was then calculated from one of the intercepts of the linear function derived as the modification of the Kozeny equation.

The degree of swelling, presented on the same basis as the data reviewed above for other methods of determination, may be calculated by subtracting the specific volume of cellulose—i.e., 0.62 cc. per g.—from the effective specific volumes determined by Robertson and Mason. These authors show an average degree of swelling for three dried sulphite pulps of 238%, which increased after 30 minutes of beating to an average swelling value of 380%. These values for the unbeaten dried pulp are about three times as great as those obtained for similar pulps by either the dilatometric or centrifuge methods. For wet pulps (sulphite and kraft), the permeability method yielded average swelling values of 359 and 496% for the unbeaten and beaten states, respectively. These values are roughly twice those obtained by the centrifuge method. The effective specific volume was shown to increase with swelling power of the medium in aqueous isopropyl alcohol solutions. A relationship was found between the specific volume of the pulp and the burst factor.

The apparently abnormally high values obtained by this method are not immediately explainable. Robertson and Mason note that their values represent the "hydrodynamic volume" of the material in the pad—i.e., the volume denied to flow of the liquid. The possibility is noted by these authors that fibrils may immobilize a portion of the liquid and in this manner add to the effective volume of the fibers. It would appear altogether likely that this volume denied to flow of the liquid encompasses a considerable volume which does not properly belong to the swollen volume of the cellulose. The hydrodynamic volume, which has been found to be a very useful concept in viscosity and drainage considerations, should be distinguished from the actual volume of the swollen fiber, which may be a basic criterion for the plasticity of the fiber. It is clear that immobilized water not actually in the fiber will play no part in plasticizing the fiber with consequent alteration in its physical properties. Due consideration should be given to this viewpoint in the consideration of the permeability method and the data derived therefrom, prior to any interpretation with regard to the degree of swelling of the fibers.

## MISCELLANEOUS

The volume swelling of cellulose has been measured by Jayme and Steinmann (*17*) and by Bergek (*30*), using the increase in thickness of a package of sheets under some pressure to calculate the increase in volume. The method appears to have some merit in the approximate measurement of high degrees of swelling, as in mercerizing solutions, but is not capable of yielding sufficiently accurate results of swelling in water. Sedoff, Holmberg, and Jahn (*21*) have measured the retention of water by pulp pads under high pressure. Nakano and LeCompte (*22*) proposed the loss in viscosity on boiling a pulp suspension as a measure of the real hydration of the pulp. Schwalbe (*23*) considered the reactivity of a pulp, as measured by the rate of hydrolysis in dilute hot acids, as a measure of the swelling ability of that pulp. Consideration has also been given to the take-up of metal hydroxides (*24*), hygroscopicity (*25*, *26*), heat of wetting (*27*), and absorption of dyes (*11*) as possible methods of measurement.

## SIGNIFICANCE OF FIBER SWELLING

The detailed effects of the swelling of cellulose by water and aqueous solutions of alkalies and acids on the x-ray diffraction diagram has been thoroughly reviewed (*28*). Swelling may be wholly intermicellar, as in the case of water, as a result of which there appears only an amorphous pattern superimposed on the original crystal pattern. Swelling of cellulose in strong alkalies

is partly intramicellar, producing a new crystal pattern together with the superimposed liquid pattern. Strong acids produce unlimited swelling with consequent complete disappearance of the crystal structure.

It would appear, therefore, that water produces swelling as a result of penetration into the amorphous areas of the cellulose structure only. Exchange reactions of cellulose and heavy water (*28*) have shown that water can penetrate the crystalline areas also without, however, affecting the spacings in such exchanges. Various theories have been discussed concerning the general mechanism of swelling of cellulose, including surface electrical charges, selective ion adsorption, etc., but it is likely that the cellulose-water system should be regarded in the same light as, for example, a polyvinyl chloride-benzene system where adsorption and immobilization of the swelling medium must suffice as an explanation (*29*). Although the swelling by immobilization of liquid among segments of the polymer chain is essentially thermodynamically neutral, adsorption is exothermic and, hence, swelling of cellulose decreases in water markedly with increase in temperature.

Highly crystalline polymeric materials are known to be relatively inflexible and brittle, and data are available for these properties in the case of many synthetic polymers. Unfortunately, presumably as a result of the size of pulp fibers and the consequent inherent difficulties of measurement, no data are available for the rigidity and impact strength of these fibers. Similarly, ample data are available for the flexibilizing and toughening effect of plasticizers on various synthetic resins, but no data are available for the effect of water in altering these physical properties of pulp fibers. Until such data are made available, we must assume that the cellulose-water system is analogous to a synthetic resin-plasticizer system with regard to general alteration of physical properties. If this assumption is made, and it would appear to be a quite justifiable one, then it follows that the extent of water content must be measured in order to note the degree of plasticization of the cellulose which has been accomplished. This is the basis for the importance of swelling data for the cellulose-water system, and the need for a suitable method for the determination of the degree of swelling of cellulose fibers.

It is well to examine in some detail the possible effects of greater softness and plasticity of pulp fibers on pulp preparation and papermaking. Unbeaten pulp fibers are undoubtedly relatively rigid and brittle. With such properties, deposition of the fiber must necessarily partake to a large extent of a brush-heap pattern, with a relatively high angle of weave in cross section and relatively few points of contact among fibers for later bonding during drying. Pressures exerted on such pads during manufacture into paper will result in considerable fiber fracture and, also, a large measure of spring-back which will seriously reduce the number of points of contact for bond formation. On exposure to the beating process, considerable damage is undoubtedly done to the fibers as a result of the relatively high rigidity and brittleness, before the beneficial results of beating can accrue. A higher degree of swelling in the unbeaten fiber should result in less damage during beating. The beating process itself has been shown to increase the degree of swelling of pulp fibers to a marked degree. Beating brings about a marked flexibilizing and softening action on the fiber and leads to a closer interweaving during deposition on the wire and subsequent wet pressing and, hence, a greater number of potential bonding points on drying. It is likely also that the area of individual points of bonding is increased as a result of the enhanced ability of the fiber to deform under pressure. This increased flexibility of the fiber is probably closely allied to a multifilament production in the fiber brought about by beating. Such multifilament production may result from some extension of existing lines of cleavage in the fiber, in addition to the effect of more plasticizer in the form of imbibed water.

The extent of beating is now measured by some form of freeness test, the results of which are very commonly used in the industry for both production control and research purposes. It is well recognized that several factors enter into the freeness test aside from that of imbibed water, of which probably the most disturbing is the effect of the length of the fiber and, in particular, the production of fines or debris. In addition, the extent of external fibrillation of the fiber has a very important effect and it is still rather open to question as to whether this external fibrillation has a beneficial effect on strength. It is well known, for example, that most of the strength developed during beating is attained during the early stages, when little fibrillation has been effected. It has been shown that mere agitation of fibers without beating produces very important increases in strength without any visible fibrillation.

The measurement of the degree of swelling itself would appear to be capable of yielding the desired information on papermaking quality. The method of measurement must be such as to exclude the effect of extraneous disturbing factors. For example, the centrifuge method of measurement would appear to be suspect on two counts—viz., (1) the increasing retention of surface water with increase in beating and (2) the possibility of actual extrusion of imbibed water. The water held physically immobilized in the lumen of the fiber should, if possible, be excluded from measurement, since the amount of water involved in this space may be important with some fibers. Any indirect method of measurement should not be subject to appreciable error by virtue of even a small degree of external fibrillation on the fibers. A general consideration of the methods thus far employed for the measurement of the degree of swelling leaves the impression that much further research is required in this field.

A survey of the extensive literature in the whole field of the effect of fiber characteristics on papermaking properties, and a study of the interrelationships among these fiber characteristics, points strongly to the swelling power as a basic factor in the whole problem. This is not intended to mean that all fibers, regardless of origin, may be evaluated solely on the basis of swelling power. Undoubtedly, chemical effects resulting from the delignification method used may have an important effect on the ultimate paper strength aside from the swelling value, and such effects must be further studied. We can only conjecture today as to the cause, for example, of the large difference in strength between pulps produced by the kraft and the sulphite process. The effect of these processes on tensile strength normal to

the fiber axis and on shear strength of the fiber might show that the strength of the interfiber bonds is of lesser importance than strengths within the fiber where failure may occur (*29*). Nevertheless, in the evaluation of pulps within one chemical type, in the interpretation of beating and refining effects, and in pulp and paper research generally, swelling power of pulps in water offers potential data of outstanding importance to the industry.

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# The Effect of Drying and Heating on the Swelling of Cellulose Fibers and Paper Strength


L. M. LYNE and W. GALLAY



**The effect of drying of pulp fibers on the deswelling of these fibers and on the paper strength is discussed. Drying of pulp results in a progressive loss of swelling power, which is partly irreversible, and the resultant paper increases in bulk and tear and decreases in tensile, burst, and fold. The effect of heating is similar in general to that of drying. In the manufacture of paper, the concept is introduced of the possibility of a deswelling effect due to heating considered separately from the effect of drying, and the resultant bearing on interfiber bonding is noted.**


The significance of the swelling of cellulose fibers in water has been discussed by one of us in the preceding communication (*1*). There appears to be no doubt that the degree of swelling, or the amount of water imbibed or held by the fibers is a basically important consideration in relation to pulp preparation, sheet formation, bonding, and the properties of the finished paper. The manufacture of paper involves both a swelling of the fibers during the earlier stages of the general process and a deswelling during drying of the sheet. It is of importance therefore to consider the nature of this deswelling, the factors which are known to bring about this decrease of imbibition, and its relationship to paper manufacture and paper strength. In addition, previously dried pulps are frequently used in the manufacture of paper, and the effect of this pulp drying is important.


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The swelling of cellulose in water is essentially intermicellar, i.e., the water is imbibed for the most part into the amorphous regions of the fiber without alteration of spacings in the crystalline regions (*2*). Relatively large increases in dimensions are involved in this swelling, and it is apparent that intermolecular spacings in the amorphous areas are very greatly increased. Among other possible factors, it has been shown that the lower molecular weight materials, commonly grouped under the term hemicelluloses, are of particular importance in determining the degree of swelling of the fiber (*3*). With increasing proportions of imbibed water, segments of the molecular chains are further freed to come under the influence of thermal forces, resulting probably in enhanced power of immobilizing more water in the system (*4*). Excellent examples of the importance of spacing between segments of the linear molecules are available in some of the cellulose derivatives. Cellulose itself is capable of only restricted swelling in water. The introduction of a proportion of ether or ester groups, e.g., methylcellulose or acetylcellulose, results in both a decrease in intermolecular attraction and a somewhat greater spacing. Thus methylcellulose in the proper range of etherification and molecular weight shows unlimited swelling in water i.e., it disperses to a clear sol. Interesting data on the effect of esterification on the moisture take-up are given by Bletzinger (*24*) and Harrison (*25*). As the propor-

tion of hydroxyl groups in a cellulose derivative is further converted, in general the compound is successively swollen only by aqueous alkali and then by polar organic solvents.

In reverse, as water is removed by deswelling the cellulose, the molecular segments are brought closer together. Thermal motion eventually brings about a proportion of alignment and greater intermolecular attraction. There exists undoubtedly the possibility of chemical bonding between carboxyl and hydroxyl groups to yield cross linkages. Hemicelluloses which have been extracted from cellulose fibers by alkali, dry to horny brittle masses which are very difficult to redisperse, except in concentrated alkali. The effect of drying of cellulose fibers on swelling and on paper strength is of interest from the fundamental point of view and of considerable importance in practical papermaking.

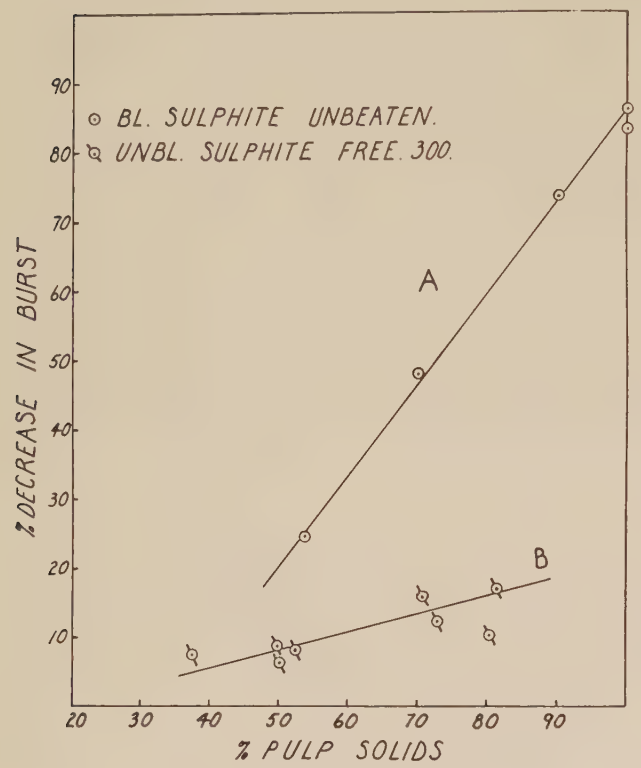



*Fig. 1. Per cent change in burst on drying pulp*

Cellulose is hydroplastic and not thermoplastic and, in contrast to most linear polymers, the degree of swelling cannot be enhanced by heat. Since the adsorbed water is the most strongly held and adsorption has a strongly negative heat coefficient, the influence of temperature on the swelling of cellulose might be expected to be very great. Intermolecular attraction is undoubtedly greatly increased as a result of the removal of at least the outer molecular layers of the film held by adsorption. The effect of heating on the swelling of cellulose fibers and on the paper strength is of great interest in the manufacture of paper.

## EFFECT OF DRYING ON SWELLING OF CELLULOSE FIBERS

It is well known that the drying of pulp brings about changes in the properties of the fibers which do not revert wholly to the original condition even after prolonged soaking. This change has commonly been related to paper strength, but the direct effect of drying on the degree of swelling of the fibers is very marked. Jayme (*5*) measured the effect of drying on the swelling of unbleached sulphite which had not previously been allowed to dry. Swelling determinations were carried out by the centrifuge method, and the results are expressed as the per cent weight of water taken up on the weight of dry fiber. The degree of swelling of the original pulp, 30.2% solids, was 159.1%. After air drying to 91.6% solids, the degree of swelling was reduced to 107.3%, and after drying for 6 hours at 70°C. to 98.6% solids, the degree of swelling was further reduced to 98.7%. These results show an irreversible hardening or "cornification" of 32.6 and 37.9% of the swelling value for the original pulp. This irreversibility was slightly reduced after an hour of soaking at 20°C. Soaking of a dry pulp in water showed (*5*) a rapid degree of recovery during the first few days followed by slow recovery to an equilibrium after about 20 days. The irreversible hardening on drying after treatment of bleached spruce sulphite with varying concentrations of sodium hydroxide has shown interesting results (*6*). The per cent hardening based on the swelling value of the undried pulp was found to go through a minimum in the pulp treated with 3% alkali and a maximum in the pulp treated with 10.5% alkali. The explanation given for these findings was based on the effect of hemicellulose extraction at the lower alkali concentration and the formation of hydrate cellulose on drying after swelling at the higher alkali concentration. This constitutes further evidence for the important role of hemicelluloses

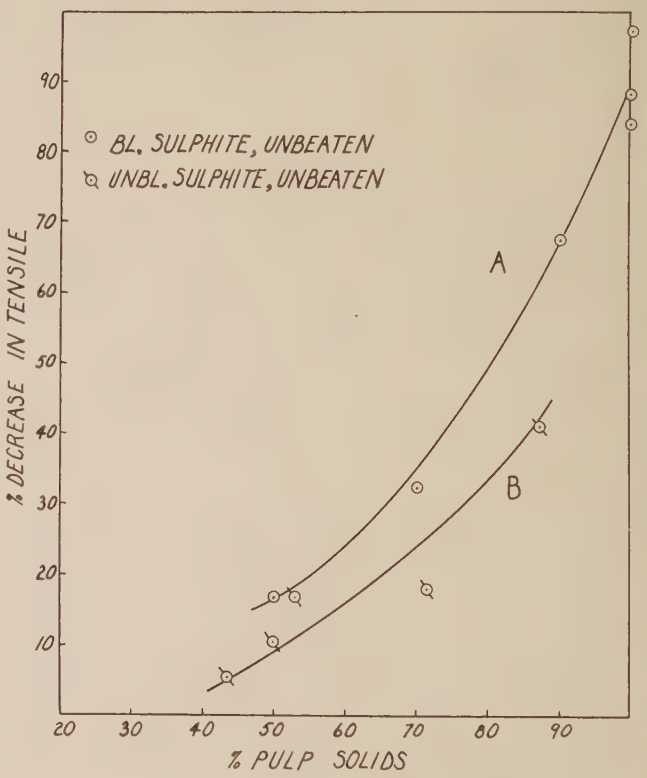



*Fig. 2. Per cent change in tensile on drying pulp*

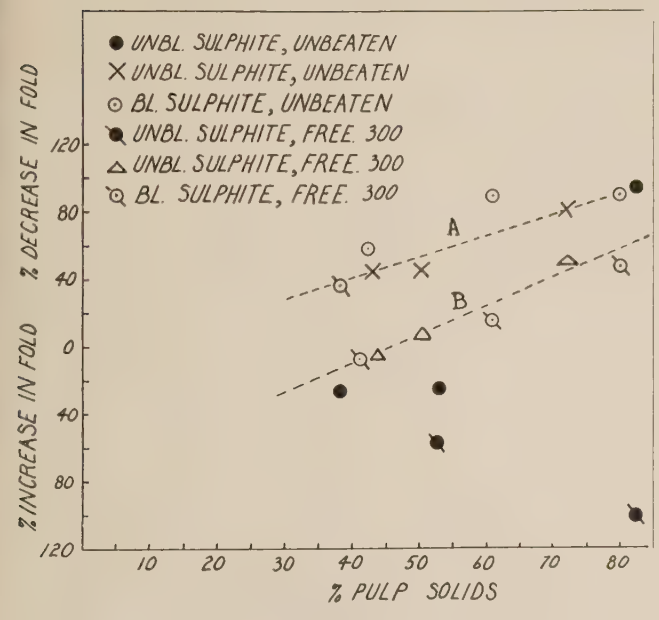
in the irreversible hardening effect, and is in agreement with other evidence as to the passivity to esterification of pulps refined by cold alkali extraction. Kress and Bialkowsky (*7*) noted that beaten pulp on drying shrinks to a dense horny mass which is difficult to redisperse on soaking. Katz (*8*) noted that pulp dried at high temperatures loses some of its most valuable papermaking properties and that these effects of desiccation are only partly reversible. It has been stated (*9*) that repeated wetting and drying progressively reduce the swelling power of viscose fibers. Robertson and Mason (*10*), using a permeability method for the measurement of swelling, showed clearly the large reduction in swelling of pulps following drying. Campbell (*11*) has discussed the effects of drying on intermolecular attraction and has expressed the interesting viewpoint that cellulose in the undried state is in the natural or unstrained condition, whereas drying results in a condition of strain as a result of the additional intermolecular attraction in the fiber.

### EFFECT OF DRYING ON PAPER STRENGTH

The effect of drying of pulp in reducing paper strength is well known in the industry generally. Nevertheless it would appear that relatively few data have been published giving quantitative effects.

The effect of drying of pulp on the bursting strength of paper is very marked. Data secured in a survey of mill pulp drying (*12*) showed large losses in burst, ranging up to 73% of the strength of the original wet pulp. The relationship of dryness of pulp and bursting strength approximated the linear.

Data obtained in our laboratory are of interest in this connection. Wet sulphite pulp in lap form was disintegrated by hand and spread out to air-dry. Portions of the pulp were made into handsheets after intervals of drying, and moisture determinations were carried out on portions of each sample. The solids content of the pulps used ranged from 30 to 90%, and 100% solids was obtained by oven-drying a further sample. Curve A of Fig. 1 shows the results obtained. It is noted that there is a linear relationship between the per cent loss in bursting strength and the dryness of the pulp. Only 15% of the original strength remained in the oven-dried sample. A similar linear relationship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× UNBL. SULPHITE, UNBEATEN
⊙ BL. SULPHITE, UNBEATEN
UNBL. SULPHITE, FREE. 300
△ UNBL. SULPHITE, FREE. 300
BL. SULPHITE, FREE. 300
A
B
% INCREASE IN FOLD % DECREASE IN FOLD
120 80 40 0 40 80 120
10 20 30 40 50 60 70 80
% PULP SOLIDS

*Fig. 3. Per cent change in fold on drying pulp*

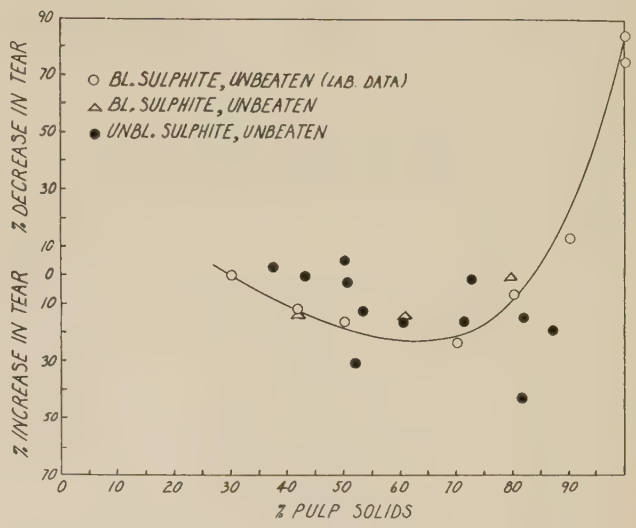

○ BL. SULPHITE, UNBEATEN (LAB. DATA)
△ BL. SULPHITE, UNBEATEN
● UNBL. SULPHITE, UNBEATEN
% INCREASE IN TEAR % DECREASE IN TEAR
90 70 50 30 10 0 10 30 50 70
0 10 20 30 40 50 60 70 80 90
% PULP SOLIDS

*Fig. 4. Per cent change in tear on drying pulp*

of the same order was obtained for unbeaten pulps observed in the mill survey noted above. Curve B of Fig. 1 shows results obtained in the mill survey (*12*), using beaten sulphite pulps. It is noted that the progressive loss in bursting strength with increased pulp dryness is much less on a beaten pulp, amounting to a loss of only 20% of the original strength at 80% pulp dryness. It is apparent that the effect of beating following partial drying assists greatly in the reversion of the pulp to a state of greater swelling ability. Babbitt (*13*) has shown that vacuum-dried pulp possesses higher strength than air-dried pulp when both are beaten, and a similar conclusion was reached by Kehoe (*14*). Elsewhere it has been stated (*15*) that vacuum-dried and air-dried pulps are equal in strength, but both are weaker than wet pulp. It has been shown in several instances that strength of the pulp is not affected by the rate of drying, but rather by the degree of drying attained. Cameron (*16*) found that oven-dried pulps were about 10 to 15% weaker than air-dried pulps.

The effect of drying of pulp on tensile strength is similar to that noted for burst. Tensile strength is less affected by drying, if the pulp is beaten prior to sheet manufacture. It has been stated (*13*) that sulphite pulp suffers a greater decrease in tensile strength than sulphate. Wrana (*17*) showed that the tensile strength decreases slowly using pulps of increasing dryness up to 85 to 90%, and then much more rapidly. Data obtained in our own laboratory are shown in curve A of Fig. 2. The procedure used was the same as that employed for the data on bursting strength. It is noted that the rate of loss of tensile strength increases with the extent of drying of the pulp, and that about 90% of the original tensile strength has been lost by oven-drying. Curve B of Fig. 2 shows data obtained in the mill survey previously mentioned. As in the case of burst, lower

losses are shown as a result of beating the partially dried pulps and consequent recovered swelling.

The effect of drying on fold endurance shows a similar trend, but few data are available. Figure 3 represents data obtained in the same mill survey (*12*), curve A for unbeaten pulp and curve B for beaten pulp. The data

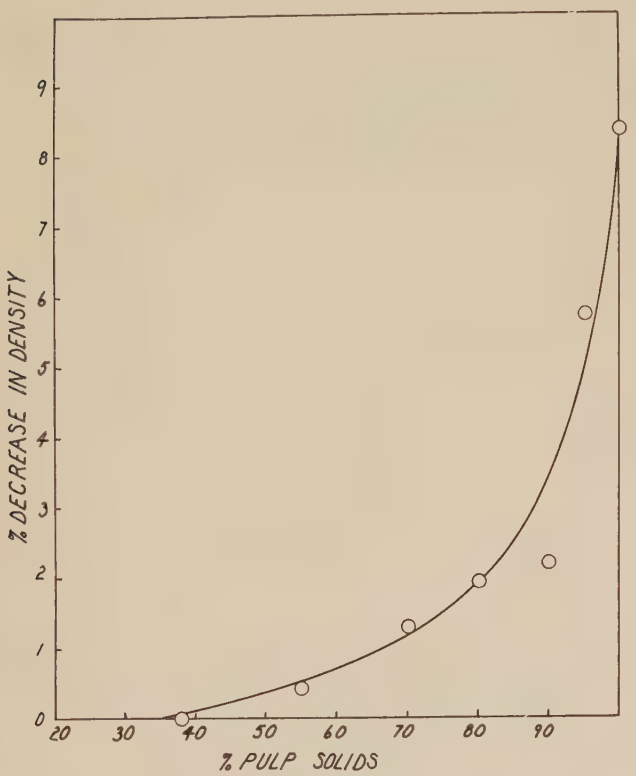



***Fig. 5. Per cent change in density on drying pulp***

are somewhat erratic, but the trend is clearly toward a weaker fold endurance with increased drying.

Babbitt (*13*) found that the tear strength of a sulphite pulp increases slightly up to 85% solids, and then shows a sharp decrease. These pulps were beaten prior to sheet manufacture. In Fig. 4, the curve relating tear strength to dryness of pulp is drawn through points representing data obtained by us, and mill survey data (*12*) are also shown.

The laboratory data show a regular reproducible relationship. The data of the mill survey were obtained from several sources and were not subject to precise laboratory control. The results obtained from mill data show quite irregular scattering and illustrate why some confusion has existed in this relationship. It is noted from the laboratory data that the tear strength increases up to about 60 to 70% solids, following which the tear strength decreases sharply up to 100% solids. The increase in tear with decreased bursting strength for a partially dried pulp is well known. The large decrease in tear in thoroughly dried pulps results presumably from an embrittlement of the fiber and an excessive slippage resulting from lack of bonding.

It is generally known that dried pulp produces a sheet of higher bulk than undried pulp. Figure 5 shows the increase in density with increased pulp dryness. The data were obtained on sheets made in accordance with the procedure given above in connection with bursting strength.

Softness of paper is closely related to the extent of bonding for any given pulp. Figure 6 shows the relationship between softness and extent of pulp drying. It is noted that the rate of increase of softness becomes greater at about 70% solids and very rapid above 85% solids in the pulp used. The softness was determined on the Clark softness tester.

## EFFECT OF HEATING ON THE SWELLING AND STRENGTH OF CELLULOSE FIBERS

Heating of pulp suspensions in general results in a decrease in the degree of swelling. Renaud (*18*) found that heating a pulp suspension to a temperature over 60°C. resulted in a loss in swelling power which is partly irreversible. Jayme (*5*) found an appreciable decrease of swelling of pulps after boiling. Nakano and LeCompte (*19*) noted that boiling a pulp suspension resulted in lesser wetness, in less affinity for water, and in faster drainage. It was found that the recovery was slow and incomplete, reaching a maximum of 50 to 75% of the original decrease after 30 to 40 days. LeCompte found that agitation during the boiling neutralized the dehydrating effect, and that agitation assisted greatly in recovery. It would appear from these data that there is a specific mechanical effect or a working of the fiber which prevents to a large extent the shrinkage which otherwise occurs. This working appears to assist also in the recovery of swelling, unless it constitutes a mild form of beating. Lewis and Gilbertson (*20*) found that swelling is favored at lower temperatures. Beating proceeds more rapidly at lower temperatures, and the resultant pulps possess higher strength. As a result of more rapid beating and the production of an improved condition of the pulp to withstand mechanical

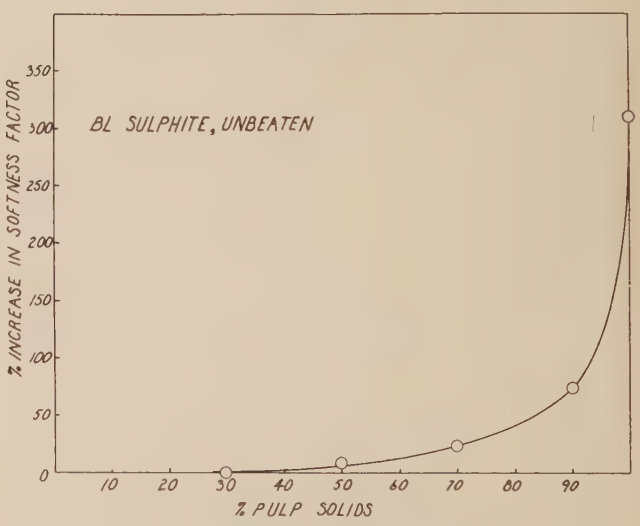



***Fig. 6. Per cent change in softness on drying pulp***

action, less damage is done to the fibers. Jayme (*6*) showed that the degree of swelling decreases materially with increase in temperature from 2 to 28°C. Nakano and LeCompte (*19*) found that the sheet made from boiled pulp is weaker and softer than that from untreated pulp. Clark (*21*) on the other hand found the

strength of the resultant paper is not decreased by heating a beaten stock. Jayme (*5*) found that refluxing a pulp for 1 hour resulted in decreased tensile and bursting strengths, decrease in fold endurance, and an increase in tear. These pulps were heated after various periods of beating.

With further regard to the decrease in swelling brought about by the heating of cellulose, it is significant to note that the heating of a solution of methylcellulose results in such extensive de-swelling as to bring about precipitation of the cellulose derivative.

## DEVELOPMENT OF BOND FORMATION DURING DRYING OF THE SHEET

Simmonds (*22*) has reviewed extensively various data concerned with the drying of paper. Water removal from the wet web may be divided into three overlapping stages. The rate of drying is relatively constant during the evaporation of free water held mechanically among the fibers. The rate then decreases as water removal is governed by diffusion of the imbibed water to the surface of the fiber and then decreases rapidly when most of this water of swelling is removed. The points of inflection in this rate curve vary in position markedly with extent of beating. Stamm (*23*) has expressed the view that shrinkage of the fibers and bonding among fibers set in as the imbibed water is removed, and that there are thus two opposing forces involved in the final phase of papermaking. The well-known theories of

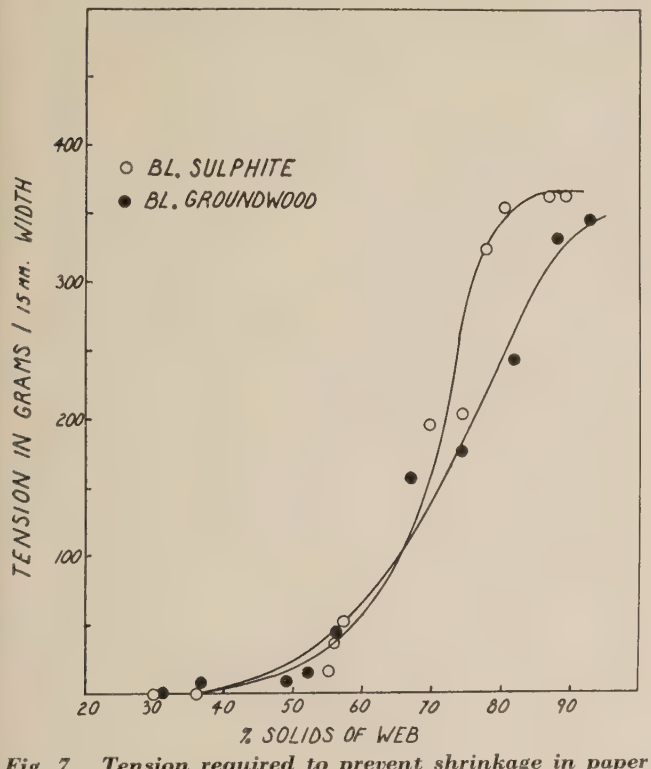
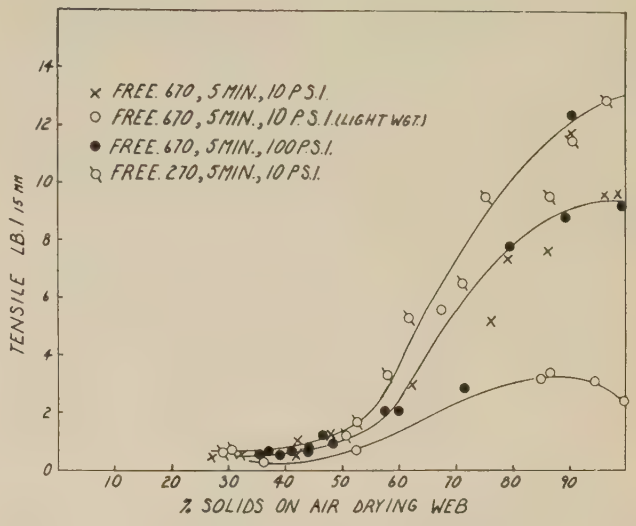



***Fig. 7. Tension required to prevent shrinkage in paper***

Campbell (*11*) on the mechanism of bond formation deal with the basis of interfiber adherence on drying.

The rate at which bonding develops during drying of the web, or the actual extent of bonding at various stages of dryness of the paper web, is a matter of considerable interest. Drying is accompanied by a shrinkage of each fiber, and the integrated effect is shown by a very considerable shrinkage of the web as a whole, particularly in the cross direction. The differential shrinkage in machine and cross direction will depend, as is well known, on the orientation of the fibers, in view of the fact that most of the shrinkage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TENSILE LB. / 15 mm.
% SOLIDS ON AIR DRYING WEB

***Fig. 8. Rate of tensile development on drying unbleached sulphite***

takes place normal to the fiber axis. Since bonding sets in during drying, the relationship between the extent of shrinkage and the water content of the web is of particular importance.

This relationship was determined by a measurement of the stress required to balance the force of shrinkage over a wide range of moisture content. Since handsheets were used, differential shrinkage in various directions was essentially obviated. Handsheets were prepared in a Williams sheet machine and pressed to 30% solids. These sheets, trimmed to 7 by 7 inches in area, were then cut into strips 15 mm. wide, and subjected to the shrinkage measurement after varying intervals of air drying in an atmosphere of constant humidity. Adjacent strips were used for careful measurements of moisture content after the same intervals. In this way a relationship was set up between moisture content and time in an atmosphere of constant relative humidity, thus providing a basis for the evaluation of moisture content of the strips used for the stress measurements and eliminating errors inherent in individual moisture determinations. For the measurement of the force of shrinkage an apparatus was used by means of which stress could be applied to the strip just sufficient to balance the shrinkage force and maintain constant length of the paper strip. The apparatus is a modified Schopper instrument designed for the testing of the shrinkage and expansion of paper. The strip under test is secured between two clamps, the lower of which is fitted to the end of a rigid rod permanently secured to the stand of the instrument. The upper clamp is attached to a tension rod to which is fixed a cord passing over a pulley and carrying an adjustable weight. The upper clamp is also connected with the registering device which may be used to indicate stretch or shrinkage. Stretch or shrinkage is indicated by a pendulum

which moves from its zero position in the center between two scales on a graduated quadrant, either to the right or left. Each division represents 0.05% stretch or shrinkage. The wet-paper strip was fixed between the clamps, the zero position adjusted, and then this zero position of the pointer was continuously maintained by counterbalancing the force of shrinkage through the addition of mercury from a buret to a vessel attached to the cord from the tension rod. Readings were taken of the weight of mercury required to counterbalance the shrinkage after various time intervals. These results were then interpreted as noted above on the basis of the moisture content of the paper.

The following tables show the results obtained for bleached sulphite and bleached groundwood.

**Table I. Shrinkage Force in Bleached Sulphite**

| *Solids, %* | *Tension, g./15 mm.* |
|---|---|
| 35.6 | 0 |
| 55.5 | 18.2 |
| 56.0 | 33.8 |
| 56.5 | 53.0 |
| 69.2 | 191.5 |
| 74.0 | 218.5 |
| 77.0 | 324.0 |
| 80.0 | 359.0 |
| 86.2 | 369.0 |
| 89.5 | 369.0 |

Figure 7 shows the results obtained, in graphical form, for bleached sulphite and bleached groundwood. It is noted that shrinkage develops rapidly at about 55% solids and is apparently mainly complete at about 80% solids.

**Table II. Shrinkage Force in Bleached Groundwood**

| *Solids, %* | *Tension, g./15 mm.* |
|---|---|
| 31.2 | 0 |
| 36.4 | 8.8 |
| 48.7 | 8.8 |
| 52.0 | 16.8 |
| 55.0 | 46.6 |
| 67.0 | 156.8 |
| 74.0 | 176.6 |
| 81.5 | 248.0 |
| 87.0 | 338.0 |
| 92.0 | 338.0 |

The rate at which strength development takes place on drying is of considerable interest. The solids content of the web following the presses on the paper machine ranges from about 30% at the beginning of drying to about 95% at the end of the drying procedure. The web strength prior to drying is very low and the quantitative relationship between degree of drying and proportion of strength developed is a consideration which has a direct bearing on any mechanism proposed for bonding development in paper. The method used for the determination of this relationship was the direct measurement of the tensile strengths of the web at known solids contents. Handsheets prepared in the Williams sheet machine were pressed under a definite pressure and cut into strips 15 mm. wide. The strips were allowed to air-dry in a conditioned room for varying intervals and moisture determinations were carried out on half of each strip after the same time interval as that allowed before the tensile measurement was made. Tensile strength determinations were carried out in a specially constructed tensiometer to be described elsewhere in conjunction with another research. This instrument is so designed as to allow for the continuous addition of loads over a wide range with a high degree of precision. The results are shown in Fig. 8 for unbeaten, beaten, and lightweight beaten sheets. Appreciable strength development begins at about 55% solids and increases rapidly to about 80% solids, following which the rate decreases. There are indications of a maximum tensile strength at about 90% solids in the web. It will be noted that there is in general a close similarity between the rate of strength development and the development of shrinkage tension, not only in the general form of the curves, but also in the points of inflection with respect to the solid content of the web. These points of inflection may also be related to the phases observed in the rate of drying curve mentioned above. It would appear that bonding and shrinkage both commence at the same stage of dryness, viz., that stage where free water has been essentially removed and water of swelling begins to diffuse to the surface and the degree of swelling undergoes a change. It is of course realized that these phases overlap considerably in practice. The bearing of such a point of inflection, viz., about 55% solids, on the actual degree of swelling of the fiber is of considerable interest. Fifty-five per cent solids corresponds to a degree of swelling on a weight percentage basis of 82%. This is considerably lower than the values obtained by the centrifuge method, but it is apparent that the overlapping of the two stages of drying will tend to shift the inflection point in this direction. Above 80% solids most of the water of swelling has been removed and, as in the case of rate of drying and shrinkage tension, little further increase is noted.

It was noted in an earlier section above that heating of a pulp suspension results, in general, in a partially irreversible change in the pulp, similar to that brought about by drying the pulp. In the case of the drying of a web on the paper machine and particularly in the earlier stages of drying, it is apparent that the fibers are heated in the presence of a considerable excess of water, simulating the heating of the fibers in water suspension. It may be assumed therefore that the effect of heating on the fiber is reproduced to some extent during the process of drying of the web, and that this effect may be considered separate from the effect of water removal as such.

This effect was reproduced in the laboratory as follows. Handsheets, during their manufacture, were exposed to a temperature of 95°C. in the presence of an atmosphere saturated with water for a period of about 3 minutes. This treatment was carried out before and after wet pressing in separate experiments. In a further series, the pulp was heated at the same temperature in suspension prior to normal sheet manufacture. Table III shows the results obtained on the physical properties of the sheets, expressed as percentage gain or loss in comparison with the untreated control. The handsheets were finally dried either by air-drying or by drying on a sheet drier at 90°C.

It is noted that the effect of the treatment on the web

after pressing is greater than that of the treatment before pressing. In general the burst and tensile strengths are considerably lowered and the tear strength is somewhat increased. The results of preheating the pulp in suspension are similar with a greater increase in tear strength. The preheated sheets, dried finally on a sheet drier, show similar results with considerably greater increases in tear strength.

**Table III. Effect of Preheating on Paper Properties**

| | *Heating wet web, 95°C., 100% R. H.* | | | *Heating pulp in suspension, 95% R. H.* | |
|---|---|---|---|---|---|
| | *Before pressing, air-dried* | *After pressing, air-dried* | *Dried at 90°C.* | *Air-dried* | *Dried at 90°C.* |
| Density | −2.7 | −3.7 | −3.8 | +0.65 | −1.5 |
| Burst | −4.7 | −14.3 | −10.3 | −16.6 | −25.8 |
| Tear | +7.7 | +3.3 | +23.0 | +14.3 | +15.1 |
| Breaking length | +3.9 | −13.5 | −8.8 | −14.5 | −7.7 |

The procedure used in these experiments does not differ greatly from that obtaining on a paper machine where the web is heated prior to water removal. There would appear no doubt, therefore, that the factor of heating, resulting in a deswelling and consequent change in strength of the pulp, must be taken into consideration in an examination of the general mechanism of drying and strength development. It is apparent that the time element may be of importance in a study of the relative magnitude of this heating effect prior to drying. These interrelations and their effects on bonding and on paper strength merit further study and evaluation.

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# Bound Water and Hydration


ALFRED J. STAMM



**The mechanism of the binding of water by cellulose and the effects of water on fiber-to-fiber bonding are discussed.**


A better understanding of the mechanism of the binding of water by cellulose, of the amount of water held by it under various conditions, of the intensity of the bonds, and of the effects of water on paper-sheet density and on fiber-fiber bonding is of considerable fundamental importance. Through such information significant improvements in papermaking technology can be expected.

The field is, however, one of investigation and speculation in which there is still considerable difference of opinion. This difference arises, in part, over various definitions of terms, such as "bound water" and "hydration" used in the title of this paper. It is thus as important to clarify the terminology as to discuss the intricacies of the subject.

Figure 1 shows the various ways in which water may be held by cellulose or wood. The chief concern of the papermaker is with water held by forces ranging from molecular forces through those of capillary condensation. This water is usually referred to as imbibed, absorbed, or bound water. The term "imbibed water" is the best general term to use, as it is noncommittal as to the manner of take-up. "Absorbed water" implies take-up from the liquid phase. The term "bound water" is frequently used to cover only the molecularly held or surface-bound water, rather than the total bound water. The author suggests that when the term "bound water" is used, it be preceded by either the word "total" or "surface."


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## IMBIBED WATER

Imbibed water can be quantitatively removed without changing the composition of the cellulose or wood. Water of constitution, on the other hand, is water not present as such, but that which may be formed as a result of thermal or other chemical degradation of the material. Free water at the other extreme is water held with an insignificant force. This does not mean a zero force since theoretically the water in a tumbler is held by extremely small surface-tension forces (equivalent to a

vapor-pressure depression of one-millionth of a per cent).

Although experimental differentiation between water of constitution and the molecularly held part of the imbibed water is not as definite as might be desired, it may be defined as the condition corresponding to zero relative vapor pressure. A zero relative vapor pressure can be experimentally approached only on heating at elevated temperatures. In order to remove the last traces of molecularly held water from cellulosic materials by heating, the temperature must be so high and the duration of heating so long that some thermal decomposition may occur and water of constitution be lost. Bateman and Beglinger (*3*) have shown that different drying methods remove different amounts of water from wood. Drying for 24 hours at 105°C. over phosphorus pentoxide removed 0.2% more water than drying without phosphorus pentoxide, but after 7 days the difference was only about 0.02%. Drying at 105°C. under a pressure of 55 mm. of mercury removed 0.3% less moisture in 24 hours and 0.4% less in 7 days than drying at atmospheric pressure over phosphorus pentoxide. Distilling in toluene and xylene (boiling points 111 and 140°C.) for 1 to 4 hours gave practically the same moisture-content values as were obtained by drying in an oven over phosphorus pentoxide for 5 to 7 days. Distilling in eucalyptus oil (boiling point 171°C.) increased the moisture evolved by only 0.3%. Distilling in tetralin (boiling point 207°C.) increased the moisture evolved by 4.15%, and thus showed that destructive distillation had become appreciable. The efficient heat transfer in the distillation method thus makes it possible to remove moisture much more rapidly than in drying in an oven and makes possible the use of higher temperatures. Even when the temperature is raised 70°C. above the boiling point of water, only 0.3% more moisture is lost than in drying in an oven to constant weight. From this fact it appears that the bound water retained under normal drying practice is probably less than 1%.

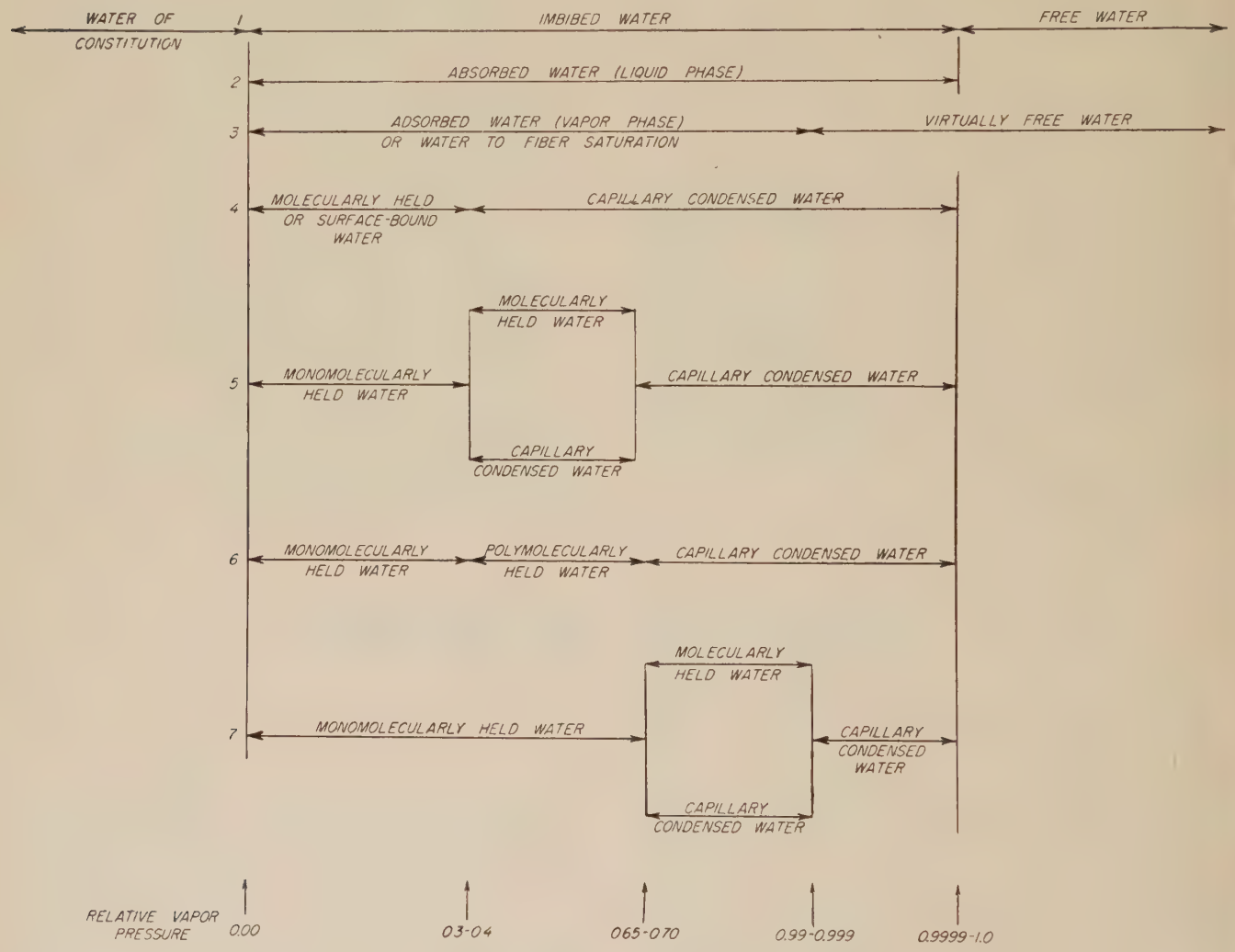


***Fig. 1. Ways in which water is held by cellulose***

The point of transition between capillary condensed water and free water is a matter of definition. Water held in the lumen of fibers with radii as great as 10 mu ($10^{-3}$ cm.) certainly should be classed as capillary condensed water (a reduction in vapor pressure of 0.01%), but the capillary-condensation concept should not be extended to the absurdity of considering a tumbler a capillary. On this basis the imbibed or absorbed water taken up by wood or a pulp may be as

high as 200 to 300% of the weight of the dry material.

## FIBER SATURATION

The fiber saturation point is defined as the water content required to completely saturate the fiber walls without filling the lumen. At room temperature it is about 30% moisture content for wood and from 20 to 30% for various pulps (*27*).

The author has estimated that the last increment of water held within the fiber wall has a relative-vapor-pressure reduction of 0.01 or 0.001 (*27*). The sigmoid-moisture-content, relative-vapor-pressure curves (Fig. 2) (*31*) normally extrapolated from sorption data ob-

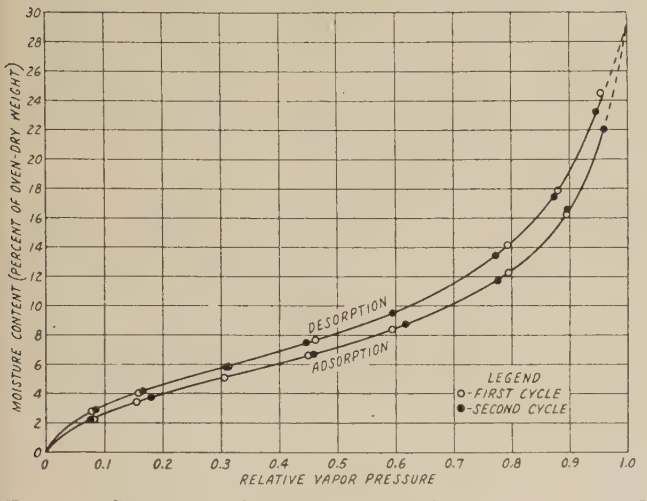


***Fig. 2. Sorption of water vapor by a commercial bleached sulphite pulp at 20°C. (31)***

tained below relative vapor pressures of 0.98, when extrapolated to a relative vapor pressure of 1.0, give intercepts practically equal to the fiber saturation point obtained from shrinkage, strength, and electrical conductivity measurements (*27*). The moisture-content, relative-vapor-pressure curves must, however, in reality become very steep above a relative vapor pressure of 0.99 to 0.999 and extrapolate to considerably higher moisture-content values, depending upon the size of the pit openings through which the water vapor has to pass. When water vapor has condensed in bottle necks, the bottles will no longer tend to fill. The capillary structure will thus never completely fill by vapor condensation (*16*). The author believes (*27*) that the sudden increase in water-vapor adsorption at relative vapor pressures of 0.99 to 0.999 is due to a minimum occurring in the volume distribution of capillary sizes between the largest transient-cell-wall capillaries and the smallest gross structural capillaries.

The fiber saturation point thus has more significance than the moisture content at unit relative vapor pressure, which is the moisture content below which wood begins to shrink (*26*, *30*) and the fibers making up a sheet begin to shrink. The over-all sheet will, however, shrink appreciably before the fiber saturation point is reached because of a drawing together of the fibers as a result of surface-tension forces (*5*). When the moisture content of wood and of cellulose fibers is reduced below the fiber saturation point, the strength properties per unit of cross section begin to increase (*33*), the electrical resistance begins to increase very rapidly (*25*), and the heat of sorption becomes zero (*27*, *29*).

## SORBED WATER

The more general term "sorbed water" is used to cover both the phenomena of adsorption (taking up of water) and desorption (losing of water). In textile research reports the term "regain" is usually used in referring to adsorption from the vapor phase.

The transition between molecularly held water and capillary water is still less definite than any of the other transitions. In fact, there may not be a point of transition. According to the simplest concept first postulated by Sheppard (*23*), the sigmoid sorption curves (Fig. 2) are made up of a monomolecular surface adsorption up to the inflection point (a relative vapor pressure of about 0.4), and then a capillary condensation that becomes more pronounced with increasing relative vapor pressures (line 4, Fig. 1). This concept is supported by the fact that the capillary radius calculated from the relative vapor pressure corresponding to the inflection point is only a little over twice the diameter of the water molecule, and thus a capillary with this radius can hold very little water that is not surface-bound. This calculation was made by using Kelvin's equation relating the capillary radius, $r$ (in cm.), to the natural logarithm of the reciprocal of the relative vapor pressure, $p_o/p$, thus:

$$r = \frac{2\sigma M}{\rho RT \ln p_o/p} \qquad (1)$$

in which $M$ is the molecular weight, $\sigma$ the surface tension, $\rho$ the density of the liquid, $R$ the gas constant ($8.316 \times 10^7$), and $T$ the absolute temperature.

The molecularly held water below 5 to 6% moisture content further represents the moisture that does not act as a solvent for such solutes as sodium chloride, glycerol, and sucrose (*25*).

This simple concept (line 4, Fig. 1) might be expected to hold for nonswelling systems. In the case of cellulose, new surface should, however, become available for monomolecular adsorption as the material swells. A number of investigators, notably Barkas (*2*), believe that water is monomolecularly held up to the point of tangency of the sorption curve with the approximately linear intermediate portion (corresponding to a relative vapor pressure of approximately 0.3, as is shown in Fig. 2). Barkas considers that the linear portion of the curve up to a relative vapor pressure of 0.65 to 0.70 involves a combination of molecularly held and capillary condensed water, and that beyond this relative vapor pressure it involves simple capillary condensation (line 5, Fig. 1).

Brunauer, Emmett, and Teller (*4*) have developed a theory for the sorption of vapors by nonswelling materials that extends the Langmuir (*14*) concept of monomolecular adsorption to polymolecular adsorption. They believe that the tangency point in question corresponds to the point of transition between monomolecularly and polymolecularly held molecules.

Babbitt (*1*) has applied this theory to the cellulose, water-vapor systems. He has shown that the simple

Brunauer, Emmett, Teller relationship, in which the number of adsorbed layers may be infinite, agrees up to a relative vapor pressure of about 0.5 with experimental data in contrast to the Langmuir relationship agreeing only up to a relative vapor pressure of 0.2. When adsorption is considered to be limited to between 6 and 7 molecular layers, the calculated values are in agreement with the experimental data up to a relative vapor pressure of 0.8. This theory of adsorption leads to the transitions shown in line 6 of Fig. 1, which differs from line 5 merely in the substitution of polymolecular adsorption for the combination of molecularly held and capillary condensed water in the intermediate range.

Although Babbitt (*1*) has shown good agreement to exist between the Brunauer, Emmett, Teller theory and experimental sorption data, he states that "an equally satisfactory agreement might be obtained by assuming that the adsorption is confined to a monomolecular layer in which, owing to the repulsive forces between neighboring atoms, the adsorbing force will vary with the number of atoms." On this basis adsorption could be monomolecular up to a relative vapor pressure of 0.7. This concept, combined with the possibility that molecular adsorption may continue up to the fiber saturation point, is illustrated in line 7 of Fig. 1.

## CELLULOSE STRUCTURE

The various ways thus far considered in which water may be held by cellulose have been postulated without regard to the accessibility of the hydroxyl groups of cellulose and to which hydroxyl groups are effective in the bonding of water. Cellulose has three hydroxyl groups to which water might attach, one primary and two secondary. From x-ray crystal-structure data and other findings, it has been postulated that native cellulose is made up of crystallites that are impermeable to water and of amorphous zones that are accessible to water (*11*, *15*). The crystallites consist of bundles of threadlike chains of anhydroglucose units with single chains extending through several crystallites (zones of orientation) and through amorphous zones, with the chains from one crystallite entering various adjacent crystallites after passing through the intermediate amorphous zone in a heterogeneous manner (*15*). The crystallites have a diameter of about 60 A. (*10*) and contain about 60 unit cells, of which about half are on the surface. If it be assumed that half the hydroxyl groups of the surface unit cells are needed for bonding to the crystallite, only one-quarter of the hydroxyl group of a crystallite can be available for adsorption. In the amorphous regions, all of the hydroxyl groups, except the few that bond one cellulose chain to another at points where they cross, should be available.

Various estimates have been made as to the percentages of different forms of cellulose that are crystalline and amorphous (*11*). Perhaps the most reliable values are those obtained from the spreading of the x-ray diffraction rings (*12*), which indicate native cotton cellulose to be 70% crystalline and wood pulps to be about 65% crystalline.

Many attempts have been made to determine the reactivity of the various hydroxyl groups of carbohydrates, including the simple sugars. The hydroxyl groups in position 1 and in position 6 in glucose have been shown, in general, to be the most reactive (*18*, *19*). The hydroxyl group in position 1 is lost in cellulose as the glucose anhydride chain link is formed between the hydroxyl groups in position 1 and in position 4. This fact makes it appear that only the primary hydroxyl group in position 6 in cellulose is highly reactive. Various studies on alkali cellulose indicate that a maximum of about 1 mole of sodium hydroxide will react with 1 mole of cellulose (*13*, *20*). If from these findings it is postulated that only 1 mole of water can be monomolecularly adsorbed on each anhydroglucose unit of cellulose (11.1 grams per 100 grams of cellulose), and that a wood pulp is 65% crystalline and the hydroxyl groups of the crystallites are only 25% available, then the primary molecular sorption of water on cellulose should be 5.7%. This sorption occurs on the desorption curve of Fig. 2 at a relative vapor pressure of 0.29 and on the adsorption curve at a relative vapor pressure of 0 33. This range of relative vapor pressures is in agreement with that corresponding to the limit of monomolecular adsorption given in lines 4, 5, and 6 of Fig. 1.

An as yet unpublished report of Tarkow and the author indicates that 1 mole of formic acid reacts with cellulose (in the number 6 carbon-atom position) per available anhydroglucose unit. Calculated values for the degree of availability of the hydroxyl groups agree well with the most acceptable values calculated by other nondestructive means (*11*). When the amount of formic acid, combined with the cellulose, is plotted against the amount of formic acid taken up by the cellulose, the data for various carbohydrates can be plotted as two straight sloping lines that terminate in a horizontal line at saturation. When the total amounts of formic acid present at saturation are converted to the same volume of adsorbed water, they correspond well with the fiber saturation points for the various cellulosic materials. When the total amounts of formic acid corresponding to the intersection point of the two sloping straight lines are converted to the same volume of water adsorbed, moisture-content values corresponding to equilibriums with relative vapor pressures of about 0.7 are obtained. Further work is needed to interpret the true meaning of the transition of slopes. The data obtained to date, however, indicate the possibility of mechanism 7 of Fig. 1 being the best representation of facts.

## HYDRATION

This discussion of bound water leads to the question of where the papermaker's hydration fits into the general picture. The papermaker uses the term "hydration" to designate the change in certain properties of a pulp that result from beating (*7*).

It was at first believed that beating resulted primarily in increased water binding or chemical hydration of the pulp. Beating, undoubtedly, increases the water binding power of a pulp appreciably between the fiber saturation point and complete saturation (equilibrium relative vapor range of 0.99 to 1.0 as shown in Fig. 1). It is well known that beating increases the amount of water retained by a pulp under conditions of simple drainage. Clark (*6*) has shown, from silver deposition studies, and Robertson and Mason (*21*) from water-flow studies, that the external fiber surface is appreciably increased by beating. This increased surface should at

least increase the ability of the pulp to hold water by capillary condensation. Increasing the amount of capillary condensed water in the relative vapor pressure range of 0.99 to 1.0, however, does not involve sufficient force to account for the greatly improved sheet properties that result from so-called hydration of a pulp. In order to account for the strength property changes it would be necessary for sizably increased amounts of water to be bonded with appreciable reductions in vapor pressure. Earlier beliefs that this is the case have been shown to be false. Carefully controlled sorption measurements by Seborg, Simmonds, and Baird (*22*) have shown that even extreme beating well beyond the useful range increases the water adsorption only from 0.2 to 3.5% from the low to the high relative vapor pressures. Such results would be expected if beating caused hydration of the external surface of the pulp (1 to 10% of the sorptive surface) in the same sense that putting the cellulose into solution (viscose or cuprammonia) and regenerating would cause chemical hydration of the pulp as a whole. This increased hydration is insufficient to account for the improved fiber-to-fiber bonding.

Of the various actions occurring in the beater, it now appears that fibrillation is perhaps the most important (*5*, *7*, *24*, *32*). This action creates an increased fiber surface by breaking the primary-wall wrappings and permitting the loosening and swelling of the fibrils making up the secondary wall. The flexibility of the fibers is also increased so that subsequent fiber-to-fiber bonds are made more extensive. A certain amount of accompanying cutting of the fibers is also desirable in improving formation.

## FIBRILLATION

Campbell (*5*) has shown how fibrillation leads to improved formation and densification of the sheet. The high affinity of the fibers for water that results in a higher interfacial surface tension between fibers and water than the high surface tension of water itself, causes the water draining through a sheet being formed on the wire to pull the fibers down to the wire. As drying progresses and water is no longer in a continuous phase but in films between fibers, surface tension forces continue to act with increased effectiveness. Two parallel fibers with a film of water with concave menisci between them are pulled together with a force equal to twice the surface tension of water. This drawing together will continue until it is balanced by the structural resistance. The structural restraint to bringing of irregular surfaces together will be much lower for the more flexible fibrils than for the fibers. Then, too, the surface-tension force that is the same between fibers of any size is far greater between fibrils than between whole fibers per unit of cross section. For example, the attractive force between fibers $3 \times 10^{-3}$ cm. in diameter is 87 p.s.i.; that between fibrils $2 \times 10^{-5}$ cm. in diameter is 540 p.s.i.; and that between fibrils $2 \times 10^{-5}$ cm. in diameter is 2480 p.s.i. (*5*). This high internal tension between fibrils far exceeds the normal externally applied compression in the paper machine. It is for this reason that a beaten pulp shrinks considerably more during the papermaking process than an unbeaten pulp and results in a denser sheet. Formation of sheets from unbeaten pulp under the high-press pressures needed to attain the density of a sheet made from beaten stock has been shown to produce practically as strong a sheet (*8*). Fibrillation in a beater can thus, in part, serve as a substitute for applied pressure in sheet formation.

Beating accomplishes another important function that accompanies fibrillation. In the process of bruising or breaking the primary-cell-wall wrappings, hemicelluloses are freed from the interior of the fiber and become adsorbed on the externally exposed fiber surfaces. These materials, which are more hygroscopic than the fibers as a whole, aid greatly in the effectiveness of the surface-tension forces that draw the structure together, and they serve also as a gap-filling glue to increase the extent of fiber-to-fiber bonds (*9*). These effects are exemplified by the fact that the beating of cotton containing practically no hemicelluloses is not so effective in improving sheet properties as beating a wood pulp that contains appreciable amounts of hemicellulose (*17*).

It now appears that the papermaker's "hydration," although definitely related to the water-binding power of cellulose through surface-tension forces, is not a matter of hydration in the sense that the word implies.

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# The Flocculation of Pulp Suspensions and the Formation of Paper

S. G. MASON

**The mechanisms whereby pulp fibers aggregate to form flocs which may persist as irregularities in the sheet structure are briefly discussed. Of several possible mechanisms indicated by the experimental evidence, it is concluded that the most important in conventional papermaking is by mechanical entanglement. The extent to which aggregation occurs is determined by a number of factors, the most important of which are the concentration, size, and shape of the fibers, and the type of motion to which the suspensions are subjected.**

In introducing this discussion it is useful to define our terminology. By fiber flocculation we shall mean particle aggregation in suspensions, by processes other than sedimentation, to produce localized variations in concentration. By formation of paper we shall mean the extent of localized variations in superficial density of the sheet—i.e., formation is a measure of uniformity. In paper these variations are most easily observed by transmitted light or "look through." The term formation is thus used in a restricted and, perhaps, misleading sense, since it differs from the broader usage of the papermaker, which embraces additional characteristics such as fiber orientation, two-sideness, "closeness," presence or absence of streaks, etc. Since this specialized usage is fairly common, the term is retained here, although to avoid confusion it may prove advisable to adopt another descriptive name should the quantitative measurement of formation become more widespread.

To give these terms meaning it is clearly necessary, in addition, to define what is meant by "localized variations"—i.e., to specify the size of the elements of volume for pulp suspensions and of area for paper, in which the variations are measured. To avoid being pedantic, we shall arbitrarily take the linear dimension of the appropriate element to be of the same order of magnitude as the length of a fiber.

Flocculation is of interest for a number of reasons. The successful recovery of white water by sedimentation methods often depends upon flocculation. The precipitation of fines upon the larger fibers is important in increasing retention of fines in the sheet, particularly with groundwood stocks in which the fines constitute a substantial part of the whole. To some extent, the rate of drainage on the wire is increased by flocculation of the fibers. Most important of all is the influence of flocculation upon paper formation, and it is this aspect with which we are principally concerned in the present discussion.

It is reasonable to assume that flocs present in the suspension immediately before the sheet is formed become frozen in the sheet structure to persist as irregularities. If this assumption is valid, it is logical that a study of the variables which enter into sheet formation must start with a study of fiber flocculation.

Many factors, other than fiber characteristics alone, are involved in flocculation; for this reason some of the ensuing remarks may appear to be outside the scope of this symposium. When a practical view of the problem is taken, however, these other factors must be considered; for it is the judicious manipulation of these factors in the design and operation of paper machines, based largely upon experience but not necessarily upon an understanding of the fundamental principles involved, which forms a part of the art of papermaking.

In order to gain an insight into the variables involved, it is important that the mechanism of aggregation be understood. Although incomplete in many details, a fairly comprehensive picture is now emerging from a number of experimental and theoretical studies in progress at The Institute of Paper Chemistry (*1–4*) and the Pulp and Paper Research Institute of Canada (*5–7*).

Fiber aggregation consists of two steps, the first being collision and the second adhesion, of the fibers.

## COLLISION PROCESSES

The normal method of keeping pulp fibers dispersed, as well as suspended, is by stirring them by one means or another. Essentially, this establishes velocity gradients—i.e., the suspension is subjected to a shearing action. This has several important consequences. In the first place, the fibers move relatively to one another and, as a result, can undergo chance collisions in much the same way as do the molecules of a gas. To take a simple example, the collision frequency in a uniform shear field such as exists in laminar motion in a suspension contained between two parallel planes, one at rest and the other moving in its own plane, is given by (*7*)

$$f = kN^2Gv \qquad (1)$$

where

- $f$ = the number of two-body collisions per unit volume in unit time
- $k$ = a factor depending upon the shape of the particles. In the case of cylindrical particles (fibers) the relevant shape factor is the length/diameter or axis ratio
- $N$ = number of particles per unit volume
- $G$ = velocity gradient (or rate of shear)
- $v$ = volume of a single particle

Equation (1) is based on a number of simple assumptions, the most important of which is that, between collisions, the fibers move independently of one another. As will become evident, this equation can apply only at low concentrations.

In more complicated patterns of fluid motion, including turbulent conditions, the collision frequency is

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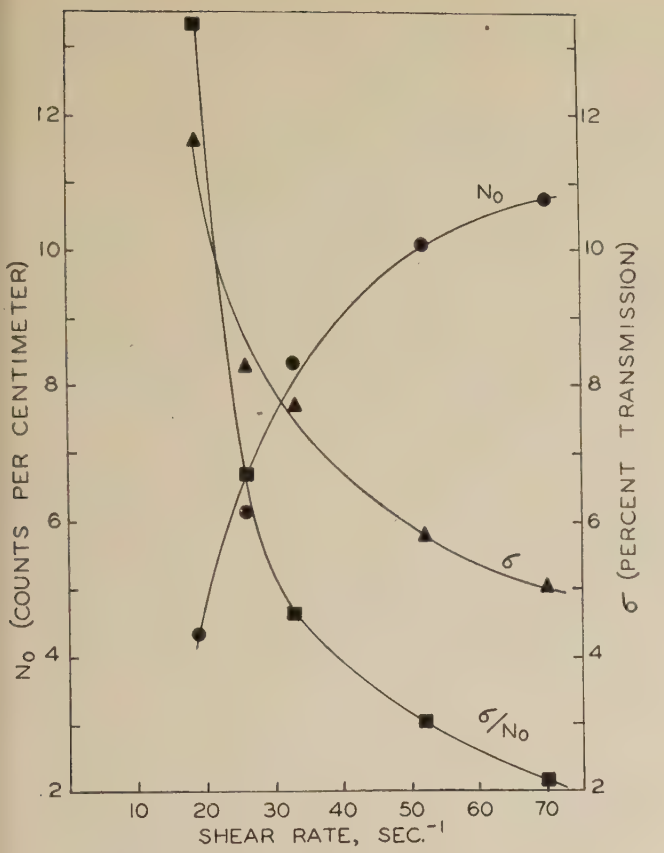


***Fig. 1. Effect of shear rate on the dynamic flocculation-dispersion equilibrium in pulp fines***

$N_o$ is a measure of the number of particles aggregates per unit volume, and $\sigma$ a statistical measure of their size. The flocculation index is taken as $(\sigma/N_o)$. After Hubley et al. (7).

given by the same relationship except that the factor $k$ is changed. Calculations based on equation (1) indicate the collision frequencies in papermaking stocks to be surprisingly high (7).

If conditions are favorable, two colliding fibers can stick together and form the nucleus of a "floc." The nucleus can grow in size by further collisions. The growing floc, which acts as a single particle, is subjected to disruptive stresses generated by the shearing action of the liquid, and a point is reached beyond which additional growth ceases. One would anticipate from these simple considerations that:

1. At a given rate of shear, a dynamic equilibrium is established between flocs being continuously broken down and built up.
2. The average number of fibers in a floc, which may be taken as a measure of the degree of flocculation, decreases upon increasing the shear rate. A similar effect is produced by increasing the viscosity of the medium.

As will be seen from some of the experimental evidence discussed later, the general validity of this line of reasoning has been confirmed for dilute suspensions.

A second important effect of shear is to cause rotation of the fibers in well-defined orbits (7). These rotations are predicted from hydrodynamic theory and, generally speaking, have been observed experimentally. The details of the rotations are complicated (7) and need not concern us here, but from the nature of this motion, it follows that the volume described by a rotating fiber is considerably greater than its actual volume. Roughly speaking, the effective volume of a rotating cylindrical particle in a stirred suspension is equal to

**Table I. Critical Concentrations for Free Fiber Rotations in Pulp Suspensions**

| *Axis ratio* | *Consistency, g./100 ml.* |
|---|---|
| 20 | 0.125 |
| 30 | 0.055 |
| 40 | 0.031 |
| 50 | 0.020 |
| 60 | 0.014 |

that of a sphere whose diameter equals the length of a particle. On this basis it is readily shown that

$$\frac{\text{effective volume of rotating particle}}{\text{actual volume}} = \frac{2r^2}{3} \qquad (2)$$

where

$r$ = the axis ratio

When the "effective" volume fraction exceeds unity, the particles are no longer able to undergo free rotation since sufficient room for them to move is lacking. Under these circumstances, the orbits of the rotating particles will intermesh continuously; the particles themselves will undergo collisions of a somewhat different kind than the chance collisions mentioned above. To distinguish between the two, we will refer to the second kind as forced collisions. It should be borne in mind, however, that the transition from chance to forced collisions is probably not sharply defined.

The concentration above which unrestricted motion of all the fibers is no longer possible is defined as the critical concentration. This concept is useful in dealing with solutions of long-chain molecules where rotary thermal motion plays a role analogous to that of the shear-induced motion in suspensions of large particles. In the solutions, rapid changes in properties occur as the result of intensified molecular interaction when the concentration is increased above the critical value.

In explaining various properties of pulp suspensions, including the tendency to flocculate, the concept of the critical concentration appears to have been overlooked at least in the published literature. In Table I the critical concentrations of monodisperse pulp suspensions of various axis ratios are given. The values are cal-

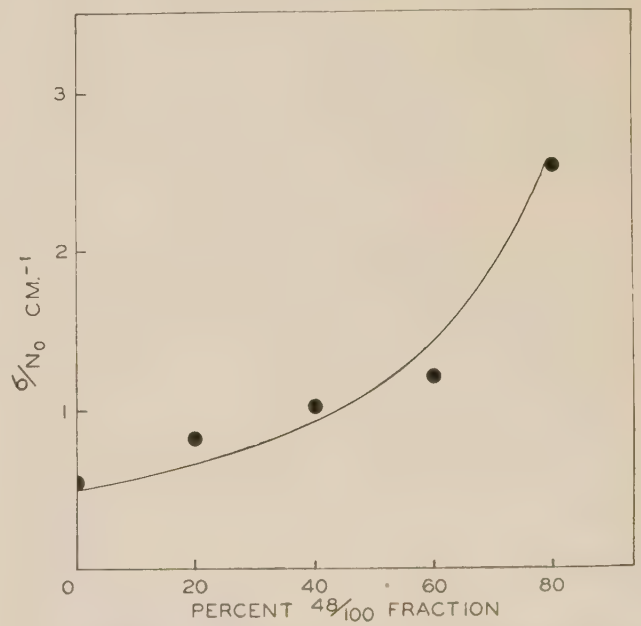


***Fig. 2. Effect of fiber length on flocculation index at a shear rate of 16 sec.$^{-1}$, and a consistency of 0.06% (6)***

culated from equation (2), assuming the swollen fiber volume to be 3 cc. per gram (7). Although the critical concentration should be more properly regarded as a region than as a sharply defined point, it is clear that, in papermaking operations, the suspensions are invariably handled at concentrations considerably in excess of the critical values. In papermaking stocks, therefore, attention must be given to the effect of forced as well as chance collisions, especially in considering flocculation phenomena.

Since the critical concentration varies inversely as the square of the axis ratio, it is clear that both the concentration and the axis ratio are important factors in any phenomena arising from forced collisions.

## MECHANISM OF ADHESION

When the fibers come into contact with one another, there are two possible ways by which they can stick together. Perhaps the more obvious is by interparticle attraction in the same way, for example, as the particles of a coagulated sol are held together. For convenience, we shall call this chemical flocculation. In most of the experimental work which has been carried out thus far, this aspect has commanded most attention. The other is by intermeshing or mechanical entanglement and, to distinguish it from the first, will be called mechanical flocculation. It is the latter to which papermakers probably refer when they speak of clotting. From the nature of the processes involved, one would anticipate chemical flocculation to be determined in part by the surface condition and mechanical flocculation by the geometric shape of the fibers.

By analogy with other colloidal systems, we would expect chemical flocculation to be exceedingly complex. Fortunately, as is now believed, most of the flocculation in papermaking stocks is mechanical; although much experimental work remains to be done on this aspect, it is by comparison easier to visualize the factors which enter here since the process is essentially one of hooking. It is reasonable to suppose that mechanical flocculation can occur when fibers undergo chance collisions but that it will dominate under conditions of forced collisions.

## FACTORS AFFECTING FLOCCULATION

From the considerations discussed above, some of which are admittedly speculative, the following factors may be expected to govern the degree of flocculation, both chemical ($C$) and mechanical ($M$).

1. Fiber Characteristics

a. Geometrical: Average fiber length and fiber-length distribution ($C$, $M$); splits, hooks, bends, and fibrillation and other forms of surface roughness ($M$).

b. Miscellaneous: Flexibility ($M$), chemical nature of surface ($C$), presence of adhesive coatings ($C$).

2. Concentration of Fibers ($M$)

3. Fluid Variables

Rate of shear, time suspension is exposed to shear motion, amount of turbulence, viscosity of suspending medium ($C$, $M$).

The effect of some of these variables is discussed later. A familiar and important practical cause of flocculation which should be mentioned, but which is not considered further, is air bubbles. When these are present, bunches of fibers are drawn together by the surface tension of the water as discussed in a previous paper (5). In practice this effect can be overcome (5) by deaeration of the stock before it reaches the slice.

## EXPERIMENTAL STUDIES

In order to indicate the applicability and the limitations of results of the various laboratory studies to flocculation at the wet end of paper machines, it is useful to outline the principles of the experimental methods which have thus far been used.

The conventional method of measuring formation is that developed by Davis, et al. (8) and incorporated into the Thwing-Davis formation tester (9). In this device, the paper sample is placed on a turntable and is scanned by a light beam of less than 2-mm. diameter. The transmitted portion is picked up on a photocell and the fluctuating component is measured as a r.m.s. current. The ratio of this current to the average total current is multiplied by an arbitrary factor to give the formation number.

This method was used by Erspamer (3) on handsheets formed from various stocks which were held for measured periods of time in the headbox of the sheet machine, after being stirred according to a standard procedure.

Wollwage (2) passed dilute suspensions slowly down a glass tube and noted the distance traveled before well-defined flocs could be observed by the naked eye. The flow was laminar and the shear rates were low (Table II). The suspension entered the tube from a violently stirred headbox; it was assumed that the fibers were completely separated at the point of entry into the tube. No attempt was made to measure the size of the flocs. A modification of this method, employing a photoelectric technique of recording the fluctuations in concentration in the tube, has recently been described (4), but no experimental results have been published.

Hubley, et al. (6) subjected suspensions to shear in a coaxial cylindrical apparatus. The outer cylinder was rotated and a beam of light about 1.5 mm. in diameter was passed through the moving suspension. The fluctuations in intensity of the transmitted light beam were analyzed electronically in a number of ways. The most useful method of analysis provided two independent quantities, one ($N_o$) proportional to the average number of particle aggregates per unit volume, and the other ($\sigma$) a statistical measure of the linear dimensions of the particle aggregates. The combined quantity ($\sigma/N_o$) was taken as an index of flocculation.

A comparison of the conditions under which these studies were carried out and a list of the variables investigated is shown in Table II.

Erspamer and Wollwage report a remarkable agreement in their observations in spite of the difference in the experimental methods.

Both observed that increasing the temperature increases the degree of flocculation, an effect ascribable to the change in viscosity mentioned earlier.

The effect of certain additives, which, with one exception considered below, we will not discuss in detail, was found to be marked. Some additives (e.g., deacetylated karaya gum, methylcellulose and tetrasodium pyrophosphate) improved dispersion. Others (e.g., Sveen glue and small quantities of alum) caused flocculation. The various effects were considered to be

Table II

| Investigator | Method | Type of motion | Consistencies of suspensions, % | Variables studied |
|---|---|---|---|---|
| Wollwage (*2*) | Direct observation of suspensions passing through cylindrical tube. Distance traveled until visible flocs formed used as basis of measurement | Laminar flow. Shear rates varied from 0.4 to 1.2 sec.$^{-1}$ | 0.01 (whole pulps) | Temperature, dispersing and flocculating additives, beating, fiber length |
| Erspamer (*3*) | Measurement of Thwing-Davis formation number of handsheets | Damping out of stirring in headbox of sheet machine and standing in quiescent state for various lengths of time (shear rate = 0) | 0.055 (whole pulps) | Temperature, dispersing and flocculating additives |
| Hubley, Robertson, and Mason (*6*) | Fluctuations in transmission coefficient of suspension. Expressed as flocculation index ($\sigma/N_o$) containing two statistical parameters | Laminar motion in Couette coaxial cylinder apparatus. Shear rates 13 to 70 sec.$^{-1}$ | 0.02 to 0.17 (fines) 0.05 (whole pulps) | Rate of shear, additives, fiber length, consistency |

chemical, the result of changes in the interfiber attractive forces resulting from protective colloid action and/or changes in the $\zeta$-potential, or to ordinary adhesion between glutinous deposits on the outside of the fibers. These explanations must be regarded as highly speculative. This is especially true of those involving changes in the $\zeta$-potential, because of the lack of independent measurements of changes of this quantity and because of considerations discussed elsewhere (*10*).

Wollwage observed that beating increased the tendency to flocculate but did not offer an explanation. In view of the mechanisms discussed previously, it is reasonable to assume that this effect is mechanical resulting from increased fibrillation and splitting.

In the experiments of Hubley, et al. (*6*) particular attention was paid to the effect of the rate of shear. The effect of additives was also studied; and, to simplify the interpretation, the effect of mechanical flocculation was minimized by using pulp fines in most of the experimental work. The results of these studies may be summarized as follows:

1. The degree of flocculation is highly dependent upon the shear rate and decreases as the shear rate increases (Fig. 1).
2. Identical values of the flocculation index ($\sigma/N_o$) are obtained by approaching a given rate of shear from either lower or higher values, thus indicating a reproducible equilibrium state.
3. Flocculation increases with increase in fiber length. This is illustrated in Fig. 2, where the variation of the flocculation index in various mixtures of fines (pass 200-mesh) and a 48/100-mesh fraction of constant total consistency are shown. The flocculation occurring here is believed to be largely mechanical.
4. The addition of electrolytes (such as alum and thorium chloride) in quantities sufficient to lower and reverse the sign of the $\zeta$-potential have a negligible effect over the range of the shear rates studied.
5. Deacetylated karaya gum was found to flocculate fines and deflocculate whole pulps.

Whereas Erspamer and Wollwage's results leave no doubt that chemical flocculation can occur and that it can be varied, within limits, by the addition of certain materials, the evidence obtained by Hubley, et al. (*6*) suggests that the effect is appreciable only at very low shear rates. The interparticle attractive forces are probably very weak, and their binding action is destroyed by comparatively gentle agitation. There is, incidentally, no fundamental reason why similar behavior should not occur at higher fiber concentrations. From a practical point of view, therefore, in chemical flocculation the shear rate is a more important control variable than any chemical additive.

Although the effect of additives is believed to be, in general, very slight, one cannot ignore the spectacular effect of deacetylated karaya gum and other vegetable mucilages in dispersing concentrated suspensions of long-fibered stocks. This has been reported in detail by Broadbent and Harrison (*11*). The effect can be demonstrated convincingly without resorting to quantitative measurement. In their behavior, these materials are in an entirely different class from, let us say, electrolytes and clearly demand some kind of explanation. It is suggested that the effect is purely mechanical, a hypothesis cautiously advanced by Broadbent and Harrison (*11*); the mucilages act, not as protective colloids in the conventional sense, but as aqueous lubricants which coat the fibers and smooth out the surface roughness, thus allowing them to slip past one another without entanglement.

The materials form stringy gels in solution and have a slippery feel to the fingers. It is significant that the materials appear to work with fibers other than cellulose. For example, if dried clots of glass wool are wetted with a solution of deacetylated karaya gum and rubbed between the fingers, one can literally feel the entangled fibers sliding over one another.

This may serve to explain the anomalous difference between the effect of deacetylated karaya gum on whole fibers and on fines mentioned earlier. It is conceivable that dispersed globules of gum are deposited on the whole fibers, whereas the reverse occurs with fines which are concentrated in the dispersed gum. Quite apart from the practical application of these gums, it is believed that studies of their behavior may serve to throw additional light on mechanisms of fiber-fiber entanglement.

## CONCLUSIONS

Is one justified in applying the results of these studies to flocculation in paper manufacture? The answer to this question at the present time is a qualified "No." The experimental work has merely scratched the surface and has only indicated some of the factors involved. Because of experimental difficulties which have not yet been surmounted, it is not possible to reproduce the magnitudes of all of the relevant variables which are encountered in machine operation. From a practical point of view, the most important of these are fiber length and shape, consistency, and the conditions of motion to which the suspension is subjected.

In both fourdrinier and cylinder machines, the entering consistency is of the order of 0.5%. For all but

extremely short-fibered stocks, this is greatly in excess of the critical concentration.

The flow conditions vary considerably from one machine to another and are complex. In a fourdrinier machine, the suspension is subjected to an alternating sequence of low and high rates of shear, reaching a maximum in the slice, and is followed by a rapid but unknown rate of decay on the moving wire. The pattern of flow is complicated further by turbulence, the role of which is not yet understood (*7*). In a cylinder machine, on the other hand, the minimum rate of shear exists in the main body of the vat and reaches its maximum value at the instant of fixing the fibers into the sheet structure. The maximum shear rate in either case varies widely but, as an order of magnitude only, we may take it to be $10^3$ sec.$^{-1}$; this is considerably greater than in any of the experimental studies mentioned above. Thus, influences which appear at low shear rates and low consistencies in laboratory studies may be negligible at the high shear rates and high consistencies in machine operation.

Undue emphasis appears to have been given to chemical flocculation and the effect of added materials, to the virtual exclusion of mechanical flocculation. At the present time, the use of added materials to improve dispersion is of limited practical interest. It is believed that the most satisfactory approach to the problem of reducing flocculation lies in systematic studies of the influence of conditions other than those produced by added materials and, particularly, those conditions which cause mechanical flocculation.

At the outset of this discussion, it was implied that formation is an important paper property and it remains, therefore, to comment briefly on this matter. Apart from its relation to the appearance of the sheet, formation is believed to influence the strength, the printing, and, to a minor extent, the optical properties of the sheet. The view appears to be held that breaks on the paper machine are often caused by bad formation. It should be pointed out, however, that these must be judged merely as opinions, based upon broad experience and not upon systematic experimentation. Although some of these relationships appear to be reasonable, they have not yet been adequately proved.

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# Fiber-to-Fiber Bonding


L. V. FORMAN


Having discussed yesterday and the day before many of the fundamental aspects of fibers and their behavior in various environments, we come to a consideration of the bonding of papermaking fibers to each other in a sheet of paper.

The bonding between fibers in wood is determined by nature. In pulping we weaken and destroy these bonds in order to separate the fibers. In papermaking we subject the fibers to mechanical action, form them into a new configuration, and then press and dry them in order to establish the final bonds. We have some control over the bonding of fibers in a sheet. Therefore, it behooves us to be able to measure this bonding and to control it carefully.

### HISTORICAL REVIEW

During the initial formation of cellulose in the growing plant, it is believed that a precipitate is formed in the presence of water and that the hydroxyl groups of the cellulose are associated with molecules of water. As the cellulose dries, these water molecules are thought to be freed and the residual valencies of the hydroxyl groups are mutually satisfied by adjacent cellulose molecules, thus forming bonds. If this system were again placed in water, a looser form of structure in the fiber surface would tend to result through the breaking of some of these bonds and the reassociation of some of the hydroxyl groups with water molecules. This hypothesis and the idea of "partial solubility" were advanced by Urquhart (*1*).

Campbell (*2*) extended this concept by suggesting that, because of this "partial solubility," the molecules of cellulose on the surface of a fiber in water were endowed with a freedom that enabled the molecules of adjacent fibers to so orient themselves that, upon drying, many of their hydroxyl groups could bond together. He showed by calculation that, as the water is removed, surface tension caused very large compacting forces to be brought into play which would serve to increase the surfaces in contact. This is especially true with the fibrils.

Strachan (*3*) proposed a different hypothesis, putting forth his original explanation that bonding is caused by the intertwining of fibrils. Strachan's arguments were questioned by Clark (*4*) in his findings of the surprising strength developed by the bond formed when two sheets of cellophane were wetted, pressed, and dried and where no fibrils could be presumed to be present.

The findings of several other men support Urquhart's hypothesis. Among others are Wislicenus and Gierisch


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(5), Turner (6), Jayme and Froundjean (7), and Bletzinger (8). In later papers, Strachan tends away from the theory of intertwining fibrils.

The total bonded area and the strength of the fiber-to-fiber bond are major contributors to the strength of a sheet of paper, and yet these factors were not measured until comparatively recent times and, even now, the methods of measurement are subject to some controversy.

The specific surface of a pulp is one of the factors used in determining the bonded area in a sheet of paper. Several methods of measuring this property have been tried in the past (3, 9–12) but all either have been discarded or their relative merits have not been determined. Clark (13) devised a silvering technique which is still in use in a revised form (14, 15). Microscopic measurement, gas and liquid permeability, and other methods (16, 17) of measuring specific surface are available. Although, in general, the results of these methods do not agree with each other, those obtained with the silvering technique and with the technique described by Mason are coming into closer agreement as both methods are improved. The reason for this lack of agreement may be that the various methods do not measure, in fact, exactly the same property. We should remember that all measurements of fibers are a means to an end, not an end in themselves.

With regard to bonded area, Parsons (18) made use of the specific surface measurement and the Kubelka and Munk equations in the determination of the area of optical contact in a sheet of paper. Ratliff (19) showed that the area of optical contact is a function, if not a direct measure, of the area of fiber-to-fiber bonding. Parsons' method is still in use and will be discussed later in this paper.

One of the first methods suggested for the measurement of bonding strength in a sheet of paper was that of Hoffman-Jacobsen (20). This suggested method was concerned with the ratio of ordinary tensile strength to zero-span tensile strength and, expressed as a percentage, was termed "per cent adhesion." It was felt that this method was influenced by factors other than bonding strength—i.e., fiber length, etc.—and other methods were suggested. Among these are several for measuring transverse tensile strength (21–23), a shear test method (24), and a method which measures the force necessary to continue a split in a sheet (25, 26). Two methods, a measurement of shear (4) and a measurement of splitting force (27), have been developed by Clark. Another method for measuring transverse tensile strength (28) has been developed at The Institute of Paper Chemistry and appears to have considerable utility.

Modern research is seeking better methods of determining the accessibility and activity of these components of fiber surfaces which contribute to bonding between adjacent fibers in paper. Such methods as the "formic acid" test being developed at the United States Forest Products Laboratory (and described by Stamm at this meeting) should be helpful. Then, with improved methods of evaluating bonded area and bond strength, it should be possible not only to develop potential bond strength more intelligently in our pulping and refining processes, but to realize more of the potential bond strength in our forming, pressing, drying, and other papermaking processes.

## MEASUREMENT

The development of specific knowledge of a fundamental nature in the field of fiber bonding seems to have lagged somewhat behind the development of comparable information on fibers for reasons which will probably be obvious as our discussion proceeds.

Relatively speaking, the measurements of the various strength properties and stress-strain relationships for sheets of paper are fairly straightforward. But these are measurements of the behavior of a nonhomogeneous aggregate, a composite of hundreds of thousands or millions of fibers of various sizes, shapes, strengths, and surface characteristics, which attach them one to the other. The old adage that "a chain is only as strong as its weakest link" probably applies to paper in a general way. However, it is difficult to find and to identify the weak link in the chain in the case of paper. This is especially true when we are, in effect, testing many chains at the same time, chains of various sizes, shapes, and compositions which are cross-linked with each other and oriented in many directions with respect to each other and to the direction of the applied stress. Whether the location of the weak area in a sheet is determined before or after rupture, it will be found to consist of a very large number of fibers and a very large number of bonds making up a complex aggregate from a gross structure viewpoint and an extremely complex aggregate from a fine structure standpoint.

In the following discussion, the terms total surface area and bonded area will be used instead of total specific surface area and specific bonded area for the sake of convenience.

The method used in this work for determining the bonded area is based on the work of Parsons (18). In this method, the total surface area of the pulp is determined on a slush sample by means of the silvering method (15). This measurement of total surface has been discussed and needs no further comment at this time. Two sets of handsheets are then formed from the pulp sample in question, one set bonded in the normal manner and the other unbonded by replacement of the water in the wet sheet by means of acetone and butyl alcohol.

Two primary optical measurements are then made on each of these two sets of sheets—namely $R_0$ or the reflectance of a single sheet over a black cavity and $R_\infty$ or the reflectance of the sheet backed by a thick opaque pad of the same material. These measurements can be made conveniently by means of the General Electric recording spectrophotometer. By consulting charts which are based on the Kubelka-Munk theory, the scattering coefficients of the bonded and unbonded sheets may be obtained.

It is then assumed that the ratio between total surface area and the unbonded area in the normal sheet is the same as the ratio between the scattering coefficient of the unbonded handsheet and the scattering coefficient of the normal handsheet. With three of these four items determined, the fourth or unbonded area in the normal sheet can be calculated. The bonded area is

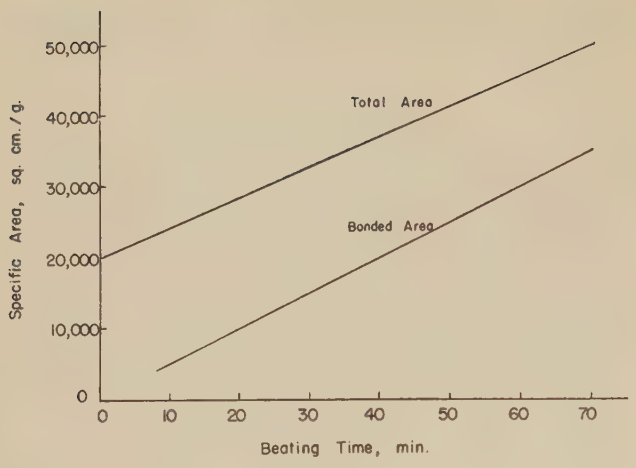

*Fig. 1*

then obtained by subtracting the unbonded area from the total area.

As originally developed, this method was applied only to bleached pulps. More recently it has been applied with slight modification to unbleached pulps. It was necessary to extend the scope of the Kubelka-Munk charts to study the effect of sheet weight and pressure during testing, the possible extraction effects of acetone and butanol on unbleached pulps, the effect of sheet-forming techniques and of the mesh of the forming wires, and the use of butanol to replace the water in a water-formed sheet rather than forming the sheet in butanol.

Assuming that we have a usable method for bonded area determination, we are next faced with the problem of measuring bond strength. The question arises as to what effect the development of fiber surface area and bonded area have on pulp strength characteristics. This leads us to a brief consideration of the determination of pulp strength characteristics. Because of the fact that there are many literature references on the subject and because a previous session of this meeting has been devoted to the subject, we will not dwell on it at this time.

It may be said that, with proper technique and proper interpretation, some of the conventional pulp strength tests provide us with at least an indirect and approximate indication of bonding strength.

## INTERRELATIONSHIP BETWEEN SHEET PROPERTIES

Because of the interdependence of fiber bonding and sheet properties, I propose to spend a very few minutes examining some of the interrelationships existing between them. There are two preliminary remarks which should be made before we enter this phase of the subject. The first is that most of the figures are not based on a single specific set of data, but represent a composite of many determinations of many pulps and are intended merely to show general trends. The second is that the whole subject of pulp evaluation is in such an evolutionary stage of development that one should pay more attention to generalities than to details at this time. (I can say this humbly as Chairman of the Pulp Testing Committee of TAPPI.)

Using the methods described earlier in this paper for the measurement of bonded area, the usual trends observed on beating softwood full chemical pulps are indicated in Fig. 1. With a standard beating and sheetmaking technique as employed in the TAPPI Standard for pulp evaluation, both total surface area and the bonded area increase approximately as a linear function of beating time. It will be noted that the actual values for surface area are larger than those obtained by the earlier procedures used for the silvering method. They are not too far from the values obtained on highly beaten stocks by the water permeability method described earlier in this meeting by Mason. Future work may alter the shape of these curves but, at the present time, Fig. 1 indicates the trends we are observing. If the total surface area and the bonded area are plotted against each other for the various times of beating, the relationship shown in Fig. 2 is not unusual. Thus, as total surface area increases, the bonded area also increases in a regular fashion.

We know, however, that sheet strength factors do not increase or decrease in this fashion as a function of beating time. The problem of obtaining a measure of bond strength, then, is not simple.

One of our first attempts to obtain an index of bonding strength was to make wet and dry tensile tests on the sheets from a conventional beater run. It was felt that the wet strength of the bonds would be so low that much of the difference in strength noted in these two tests could be attributed to bond strength. Unfortunately, using standard procedures and equipment, the wet strength of many pulps was so low that it could not be measured accurately. Thus, factors other than bonding strength were contributing relatively little to the tensile strength of the sheet. Therefore, as a rough approximation which seemed to be useful in at least some cases, the dry tensile strength was taken as an index of bonding strength.

Feeling that the inherent strength of the fibers changes during beating and that perhaps a correction should be made for this factor, the zero-span tensile strength of the various pulps was determined. The trends observed for zero-span tensile, dry tensile, and wet tensile are shown in Fig. 3.

You will note that the zero-span tensile strength increases rather than decreases as beating progressed. We have no good explanation for this increase in zero-span values. It may be that the initial density of the sheet influences the test. It might also be concluded that bonding plays a secondary role in this test. Zero-span tensile tests made on unbonded handsheets, such

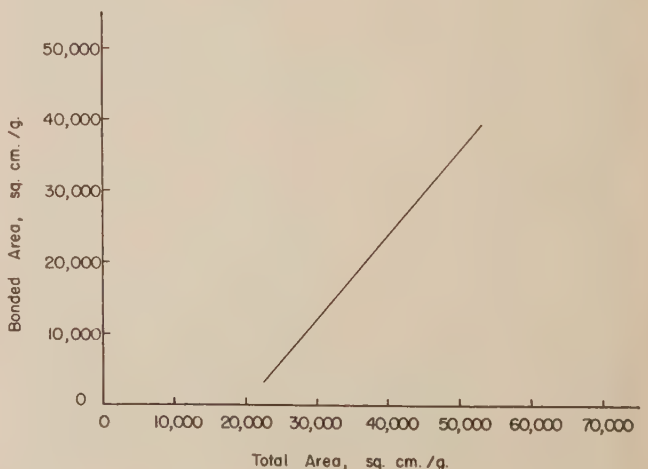

*Fig. 2*

as those used in the bonded area determination, tend to run several per cent lower than those made on the corresponding bonded handsheets. These zero-span results were obtained after literally months of work had been expended to insure parallelism and alignment of the jaws, as well as to establish and to control clamping pressure during the test. At any rate, it was decided tentatively that most of the improvement in tensile strength during a beater run was attributable to improved bonding.

Having considered the change in total surface area and bonded area, as well as the tensile characteristics, as a function of beating time, we looked at sheet density, bursting strength, and tearing strength in a similar manner (Fig. 4). Here the dry tensile and zero-span tensile strengths are repeated, together with the characteristics just mentioned. It will be recalled that the total surface area and bonded area formed straight lines (Fig. 1), whereas these properties all show curvilinear relationships (Fig. 4).

In studying these results, it was noted that the tensile data when plotted on semilogarithmic paper, gave straight line relationships (Fig. 5). Thus, on beating, the tensile strengths increased linearly as a function of the logarithm of beating time.

On further analysis of the other data it was found that sheet density, bursting strength, and tearing strength also developed linearly as the logarithm of beating time (Fig. 6).

Now, we have shown that total surface area and bonded area varied linearly with beating time, whereas sheet density, bursting strength, tearing strength, and the tensile strengths varied with the logarithm of beating time. We wondered then if tensile strength, for example, would vary as the logarithm of bonded are as well as with the logarithm of beating time. The relationship shown in Fig. 7 was noted.

Following the same line of reasoning, all the factors which varied linearly with the logarithm of beating

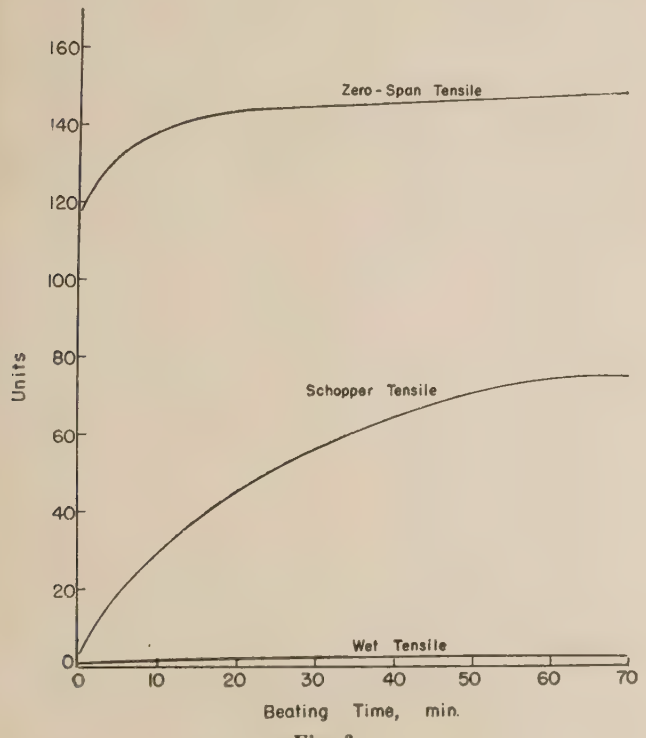


*Fig. 3*

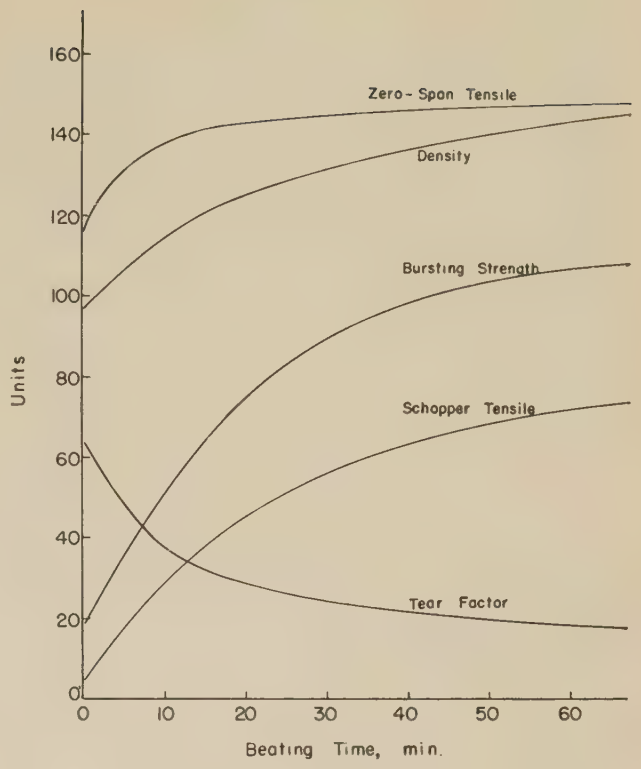


*Fig. 4*

time were plotted against the logarithm of bonded area and also against the logarithm of total surface area (Fig. 8).

Thus, we have shown typical interrelationships between beating time, surface area, bonded area, sheet density, and strength properties. It is true that the methods used in the analyses which led to these conclusions are not perfect. The surface area determination, the bonded area determination, and the zero-span tensile test need to be improved. Also, this review is based on laboratory work, largely on softwood full chemical pulps, done in small beaters with a standardized technique of sheetmaking and air drying the sheet. All of this is readily admitted. However, the curves we have shown are typical curves, based on work with many different pulps. Similar curves can be obtained with other refining equipment, such as the pebble mill, Morden Stockmaker, kollergang, etc. The absolute values will vary from one pulp to another and from one type of refiner to another, but the over-all general trends appear to be similar and significant.

On beating a pulp, the fiber area may be increased by fibrillation, hydration, and cutting, and the bonded area in sheets made therefrom tends to increase as the surface area of the pulp increases. The relative speed with which each of these three actions proceeds depends on the particular pulp, refiner, and processing conditions used. It is very difficult to segregate these actions and their effects. However, it is interesting to note the interrelationship of properties when an attempt is made to segregate cutting and hydration in the laboratory.

If two properties, such as bursting strength and tearing strength, are plotted against each other, it will be noted that, on progressive cutting of the fiber, both properties decrease. On hydrating, it is found that bursting strength increases rapidly, whereas tearing

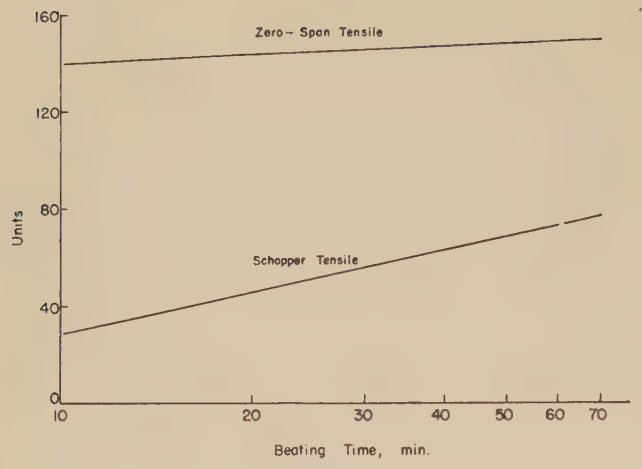


*Fig. 5*

strength either increases or at least holds its own before starting to decrease. The relationship for conventional beating and refining falls between these two extremes. There is no doubt that fiber bonding plays a great part in determining such relationships. An analysis of this type helps in comparing the beating response of two pulps in the same refining equipment. It also helps in comparing the refining action of two beaters or refiners on the same pulp. Often the reason for lack of agreement between laboratory refiners and mill refiners becomes more apparent on this type of analysis.

It should be mentioned in passing that, in the treatments just described, the cutting changed the fiber length drastically with practically no change in the freeness. The hydration reduced the freeness with practically no change in the fiber classification. When fiber bonding measurements are added to such data, our understanding of the phenomena observed will be much greater.

Because sheet density bears such an important relationship to other strength properties and to bonded area, and because it is known that wet pressing influences sheet density, some experiments have been made to elucidate this factor. To summarize briefly the results obtained to date, it has been found that wet pressing preceding a standard drying procedure has a very pronounced effect on sheet properties. With a partially beaten pulp made into handsheets, the effect of wet pressing on sheet properties is shown in Fig. 9.

It will be noted that the general trend of these curves is almost the same as that of the same properties plotted against the logarithm of beating time (Fig. 6), the logarithm of total surface area, or the logarithm of bonded area (Fig. 8). The similarity between the effect of beating with standard pressing and the effect of wet pressing at a given degree of beating (Figs. 6 and 9) is of considerable interest. Bursting strength, for example, goes through a maximum on wet pressing, just as it does on beating. From a practical standpoint, the implication of the manner in which wet pressing can supplement beating or refining is very significant. There is no comparison between the amounts of power required in the two cases. With some southern and some western pulps which are difficult to refine, and which are characterized by high tearing strength and low bursting strength, the importance of wet pressing on the machine takes on an unusual significance.

A certain amount of bonding is necessary for proper strength. The degree of bonding achieved in a given sheet depends, among other things, on the refining, the formation, and the wet pressing.

I do not mean to imply that no one is doing a good job of wet pressing today or that a high degree of wet pressing is desirable for all papers. Tissues, in which softness is desirable, are an obvious exception. However, there are many cases in which better strength could be realized at the same or even less power input to refiners if a better job of wet pressing were done.

We mentioned earlier that caliper decreases during drying. However, if we could get a good wet caliper reading after the last press, we would find an increase in caliper from that existing in the nip of the press. A wet sheet is resilient and springs back to some extent before it starts to shrink again on drying. In general, high pressures are not needed to maintain compression in a sheet while it is being dried. Perhaps it is not too fantastic to predict the use of a multiple light pressing or compacting of sheets in the drier section to at least offset the springback in the moist sheet following conventional pressing.

May I take just a moment to point to the advantages of using the semilogarithmic plot in connection with pulp evaluation (see Figs. 4 and 6). It is true that the zero-beating interval is omitted in such a plot. However, in many cases, the tear value at zero beating is not reliable or significant. With long-fibered pulp, the tear value may not be quite in line with the rest of the points after 5 minutes of beating. It is also true that the bursting-strength and tensile-strength curves are not linear after a maximum value is approached for these properties. Nevertheless, there is a substantial range of beating time between the point where the tear curve becomes linear on the semilogarithmic plot and the point where the bursting-strength and tensile-strength curves become nonlinear; this is significant because it is the

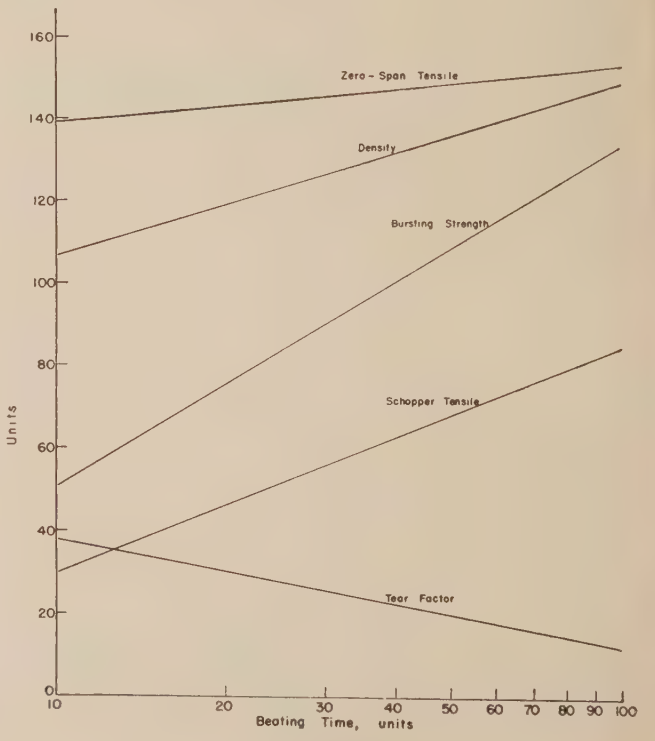


*Fig. 6*

range of general papermaking interest. Incidentally, the degree to which the experimental points fall on the lines in this semilogarithmic plot is an indication of the conditions of the equipment and of the care exercised by the operators in making the pulp evaluation.

If the range of linear behavior is established for a given pulp, the possibility of simplifying the procedure for pulp evaluation is suggested. With good technique, it should be possible to derive almost as much information from three or four sets of sheets made at well-chosen beating times as we now obtain from five or six sets of handsheets. Furthermore, the results portrayed on a semilogarithmic plot may be easier to interpret by both the technical man and the nontechnical man.

The trend of the sheet density curve in Figs. 6, 8, and 9 is particularly noteworthy. Some of you may recall the early studies of the effect of density, such as those of Doughty (*29*). Density is a simple value to determine, requiring only the measurement of weight and caliper and a simple calculation. Secondly, it is a very significant value because of its relationship to other physical properties of the paper. Two examples might be cited to illustrate the point. In one case, a pulp was evaluated in two laboratories and the results were in approximate, but not exact, agreement at the various beating times. When both sets of data were plotted against sheet density rather than beating time, the points all fell nicely on the same curves. In the second case, two pulps of widely different fiber characteristics were tested for tensile strength in the usual manner. When these same data were plotted against sheet density, the two sets of data fell on the same curve, indicating that these widely different pulps had the same tensile strength at the same sheet density.

These studies emphasize the extreme importance of wet pressing in pulp testing by means of handsheets. The effect of even small changes in sheet density is of sufficient magnitude that it cannot be overlooked. The importance of the caliper measurement is also emphasized. Current techniques and equipment should be

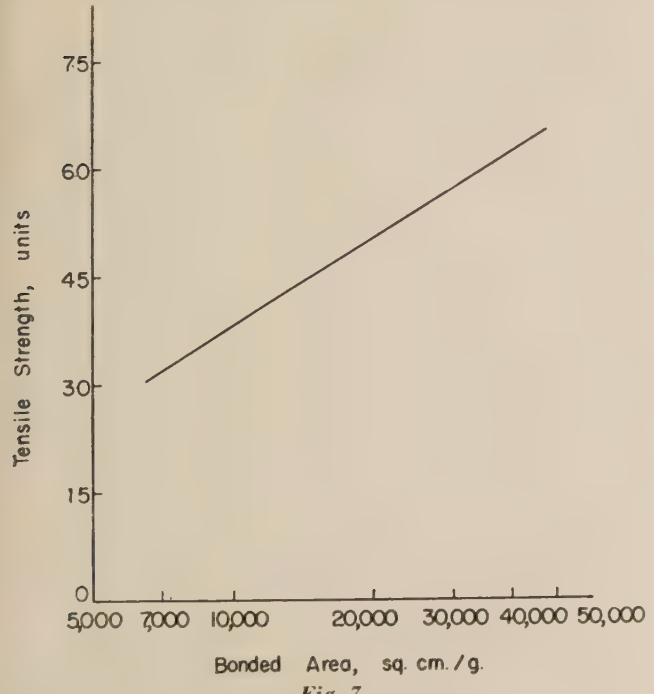


*Fig. 7*

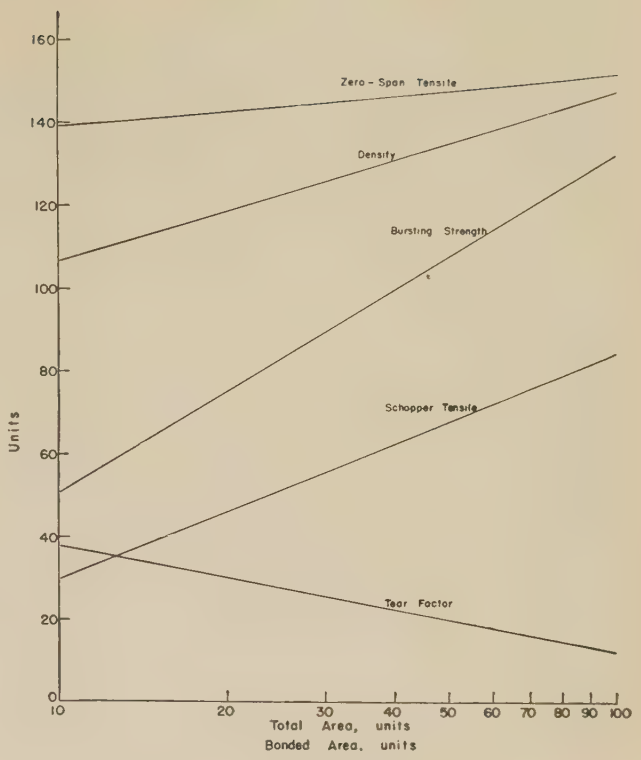


*Fig. 8*

scrutinized carefully to determine whether statistically significant results are being obtained.

In discussing density, it is difficult to know what is cause and what is effect. We know that, after wet pressing, sheets diminish in caliper and increase in density and strength on drying. The extent to which the bonded area increases as this shrinkage and drying takes place is not known with certainty as yet. The optical method of determining bonded area is not suitable for following the trend of bonded area during drying. At any rate, the total strength of the bonds increases during normal drying. It is influenced by the relative humidity of the ambient atmosphere after drying and is weakened by subsequent wetting. The use of wet-strength agents to minimize this loss of strength on wetting is well known.

## EFFECT OF PULPING AND PAPERMAKING VARIABLES ON BONDING

Before leaving this subject, let us review briefly the factors in our process which influence fiber bonding.

As fibers from different species of wood vary widely in physical dimensions and composition, we can choose our fiber furnish in such a way as to help us achieve our ends. The pulping process and the degree of cooking influences the physical behavior of fibers as well as their surface activity from a bonding standpoint. Likewise, in bleaching we do more than change the color of the pulp. We change the bonding characteristics of the fibers.

In mechanical refining, we expend considerable effort to improve the bonding tendencies of the fiber. We also help formation by adjusting the fiber length and fiber flexibility. This is important for achieving sheet uniformity and optimum opportunity for fiber contact points in the sheet. In the normal range of beating, however, only a part of the surface of any one fiber is in

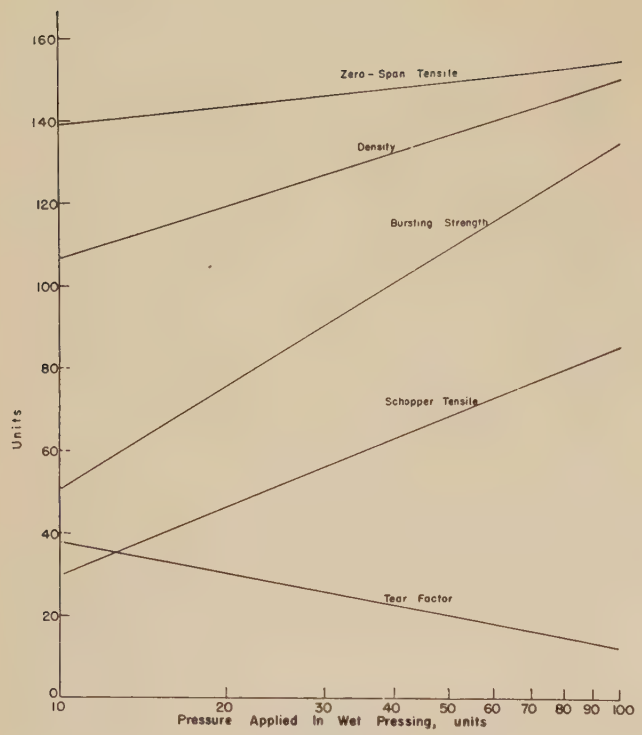


*Fig. 9*

contact with other fibers. It is at this point that wet pressing is important. It does more than remove water from the sheet. It increases contact area between fibers, leads to an increase in bonded area, and to an improvement in strength. On drying, the bonds become strong. On calendering, the fiber contact area may be increased but the bond strength may not be increased. Dry calendering is not the same as wet pressing. Too severe calendering or calendering too heavy a sheet on rolls of too small diameter may damage or disrupt some of the fiber bonding. Because of the sensitivity of paper and of fiber bonds to humidity and wetting with liquid water, the environment in which paper is converted or used must at least be mentioned in connection with such a review of the factors affecting bonding. Thus, one of our main efforts in papermaking is to establish proper bonds between fibers in the sheet. It merits serious consideration from a fundamental point of view.

## FUTURE WORK

Before concluding, I should be remiss if I did not speak pointedly to the need for more study and for more knowledge in the field of fiber bonding. It seems to me that we need coordination and integration in our attack on fundamentals related to all of the components and to the aggregate of papermaking fibers.

We are getting far enough along with our work on cellulose to worry quite a bit about crystalline and amorphous forms of cellulose. Our lignin work is coming along fairly well in terms of chemical composition, but the physical studies and the effects on fiber bonding leave many challenging avenues of study open to us. One of the greatest unknowns seems to lie in the realm of hemicelluloses. Our analytical methods are inadequate and our understanding of the composition and behavior of the hemicelluloses are incomplete. Our kraft pulping process, noted for its production of high-strength pulps, is really destructive and devastating as far as hemicelluloses are concerned. We dissolve out some desirable hemicelluloses and we create less desirable ones by degradation of the alpha portion. Our analytical methods cannot adequately distinguish between these two types of materials which are rather similar chemically.

Thus, although much more work is needed in all these fields, the lack of information relating to the hemicelluloses appears to be outstanding—and essential to solution of the fiber bonding question.

Another great need is the development of analytical techniques to be used to determine the composition and reactivity of fiber surfaces rather than of whole fibers.

In conclusion, the vital importance of this question of fiber-to-fiber bonding to the science and technology of pulp and papermaking cannot be over emphasized.

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# The Effects of Natural Beater Additives on Papermaking Fibers

JOHN W. SWANSON

**In addition to the saving of power chemical "hydration" has many advantages in regard to paper properties over that achieved by mechanical means. The Japanese have used additives for many years in the preparation of their handmade sheets. Starch has also been used, but it is not as effective as gums such as karaya, locust bean, guar, and several other materials. The results of experimental work on locust bean and guar gums are given.**

In the manufacture of many papers one of the most important processes is the beating of the pulp mixture which consists essentially of cellulose and water. Cellulose thus treated is said to become "hydrated," although very little evidence has been found for hydration in the chemical sense. The outstanding property of such beaten cellulose fibers is their ability to form strong adhesive bonds when dried in contact with one another. During the first part of the beating cycle, the fibers swell and imbibe water to a considerable extent. The fiber surface is roughened and further mechanical action splits the fiber into strands called fibrils. The fibrils, in turn, are separated into still smaller fibrils, whose dimensions may approach those of actual cellulose chains. As beating proceeds, the cellulose swells considerably, and this swelling leads to greater area and intimacy of bonding between fibrils and other cellulose fibers when the sheet is formed, pressed, and dried. This increased bonding results in a stronger paper as indicated by bursting strength, tensile strength, folding endurance, etc. This is illustrated in Fig. 1.

## EFFECTS FROM HYDRATION

Although paper made from beaten stock may be stronger, such paper shrinks more upon drying, becomes more dense, more translucent, less opaque, less compressible, and less oil receptive. These trends in properties are to be avoided if a good printing paper is desired.

The further importance of beating is emphasized by the enormous amounts of power required by the conventional beating and refining engines. Clark (*1*) states that "from 200 to nearly 2000 kw.-hr. per ton of finished paper [are required], although it is not often that a figure of 1000 is exceeded." With an annual production of over 21 million tons of paper and board, it can be seen that the cost of power for this operation is very large. Thus, it is apparent that, although beating and refining are necessary in many papermaking operations, these processes are costly and have certain disadvantages. For these reasons papermakers have long sought a means of "hydrating" cellulose fibers by chemical rather than by mechanical methods—that is to say, a material has been sought which will impart to the surface of relatively unbeaten cellulose fibers colloidal characteristics similar to those provided by mechanical beating.

Aside from affording a saving in power, a chemical hydrating material would conserve the natural fiber structure, and papers could be made which have high strength as well as higher porosity, higher opacity, better formation, better compressibility for printing, lower hygroexpansivity, and less tendency to curl and cockle. In addition, pulps so treated would drain more rapidly and faster machine speeds could be attained. Many of these properties are incompatible with high strength as developed by mechanical beating processes. Furthermore, higher percentages of inert fillers and weak short-fibered filler pulps could be used. This would conserve the increasingly scarce supply of long-fibered pulps.

## THE USE OF GUMS, MUCILAGES, AND STARCHES IN PAPERMAKING

### *Japanese Papers*

In the oriental countries, certain gums and mucilages have been used in the manufacture of long-fibered papers for many years. Until comparatively recently, however, the secret of the nearly perfect formation of handmade Japanese yoshino paper was little known. This paper is made from paper mulberry or kozo (*Broussonetia papyrifera*), gampi (*Wickstroemia canescens* Meisn.), or mitsumata (*Edgeworthia papyrifera*) fibers which have an extraordinary tendency to flocculate and form fiber knots. In 1936 Dard Hunter (*2*) revealed that vegetable sizes or mucilages are necessary for forming the sheets of Japanese paper. These vegetable sizes are obtained by water extraction of the roots of rose mallow (*Hibiscus manihot* L.), okra (*Abelmoschus esculentus*), hollyhock (*Althaea rosea*), and the bark of *Hydrangea paniculata* Sieb. By far the most widely used source of the mucilage is the *Hibiscus manihot* (sometimes called *Abelmoschus manihot medicus*). This plant, called tororoaoi by the Japanese, is an annual with a fleshy tapering root 30 to 40 cm. long and 1.8 to 2.6 cm. in diameter at the top. Blue and red varieties are known, but the latter variety is preferred because of its larger root. For papermaking purposes, the root and part of the top of the plant are ground and soaked in water for 24 to 48 hours. The mixture is then strained through cloth and added to the papermaking stock as required. The prepared mucilage, called ooshokki, is very viscous and ropy. For best results, equal quantities of the mucilage solids and papermaking fiber are used. Without this mucilage, it is almost impossible to form a good sheet of paper from unbeaten mulberry pulp because of fiber entanglement and fiber

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knots. Addition of the mucilage to such entangled fibers causes dispersion of the fibers during sheet formation. Since the war, the Japanese have been forced to seek substitutes for ooshokki because the growing of *Hibiscus manihot* competes with the growing of foodstuffs. A number of substitutes have been used, but the best of them, the bark of *Hydrangea paniculata*

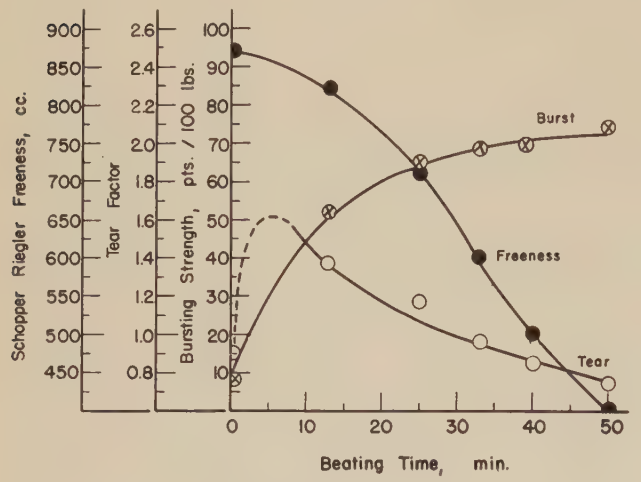



*Fig. 1. Beater evaluation curves for a bleached coniferous sulphite pulp*

Sieb., is only about 50% as effective as the mucilage from *Hibiscus*. More recently, the Japanese have crossed the *Hibiscus manihot* with a type of hemp and obtained a plant whose root can be used for mucilage

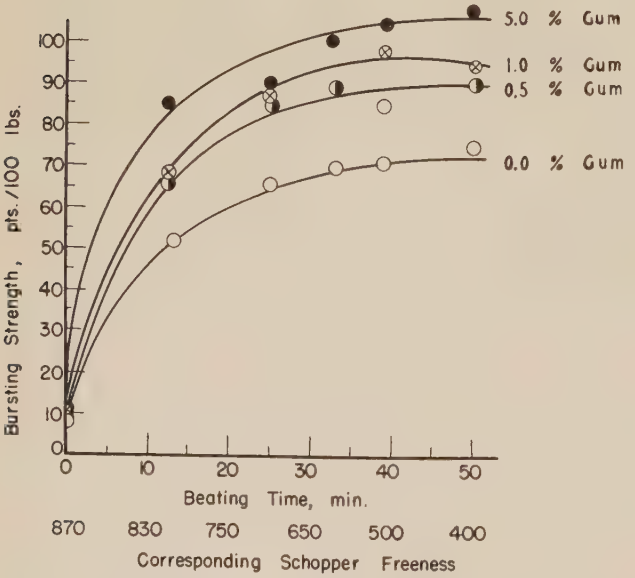



*Fig. 2. The effect of beating and locust bean gum on the bursting strength of coniferous sulphite pulp handsheets*

production and whose stalk can be used as a source of papermaking fiber.

### *Use of Starch*

Starches were used for sizing papyrus as early as 3500 B.C. and have been used off and on in papermaking for the last 2000 years.

The Japanese have found starch rather ineffective for making long-fibered papers, but rice starch is used as an adhesive in the manufacture of their shorter-fibered machine-made papers. Starch has been used in papermaking in the United States for a long time. However, there was a time not so very many years ago when papermakers held the opinion that starch was used only when the beaterman had failed to make a good pulp. In other words starch served to cover up his mistakes. This is certainly not true today. Within the last 20 years the use of starch has grown at an increasingly rapid pace until now it is one of the major raw materials for many grades of paper. The annual consumption in the United States at the present time exceeds 175,000 tons (*3*), a large part of which is chemically modified starch. Unmodified starch is cooked and added to the cellulose pulp before the actual formation of the sheet of paper. This starch is used in papermaking for two principal reasons: (a) to increase the strength properties such as bursting strength, folding endurance, and tensile strength, and (b) to supplement the beating operation. There are also several less tangible reasons for the use of starch such as improvement of erasure, decreasing surface fuzz, prevention of filler dusting, imparting of increased rattle and, with some starches, improvement of sizing. The variables involved in the use of starch in papermaking have been studied by Casey (*4, 5*), Rowland (*6*), Rowland and Bauer (*7*), Cobb and co-workers (*8*), Houtz (*9*), Kerr (*10*), and many others.

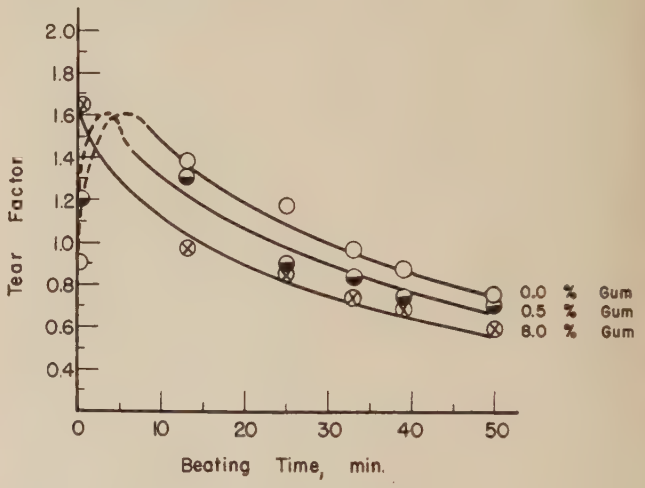



*Fig. 3. The effect of beating and locust bean gum on the tear factor*

### *Other Materials*

In England, Broadbent and Harrison (*11*) determined the effect of a considerable number of gums and of dispersing, wetting, and emulsifying agents on the sheet-formation properties of a long-fibered pulp. Irish moss, rice starch slime, dextrines, pectins, glycerin, agar, casein, carboxymethylcellulose, aluminum acetate, sodium silicate, and cellulose xanthate were found to be unsatisfactory. Various gums were also ineffective. Methylcellulose in excessive amounts gave ap-

preciable fiber dispersion and, hence, improved sheet formation. Karaya gum was found to be ineffective in its natural condition but, after deacetylation with ammonia, excellent fiber dispersion was obtained. Bassora gum, similar to karaya gum, also gave good results. These investigators noted pronounced improvements in strength properties which they attributed to the much better sheet formation resulting from these gums. The use of partially deacetylated karaya gum for maintaining fiber dispersion of long-fibered pulps has been patented by Le Compte (*12*) (assigned to the Manning Paper Company).

### *Fiber Flocculation*

Wollwage (*13*) has developed a dynamic method of measuring fiber flocculation and confirmed the dispersing effect of deacetylated karaya gum and a number of other materials on cellulose fibers. Erspamer (*14*) continued this work and found that locust bean gum and methylcellulose were more effective deflocculating agents than deacetylated karaya gum under the conditions of his experiments. Electrokinetic studies led to the conclusion that both hydration film and electrokinetic potential on the fiber are involved in fiber flocculation and dispersion. Gray and Van den Akker (*15*) have studied the mechanism of the flow of paper stock in pipes. They found that the addition of 1% locust bean gum (based upon the dry weight of unbleached kraft pulp) greatly reduced the friction of a high-consistency stock. This would be expected to lead to greater ease of pumping of high solids stock to other parts of the paper mill. de Waele (*16*) has shown that dextran, the polysaccharide synthesized by the action of *Leuconostoc dextranicum* on sucrose, is an effective fiber deflocculating agent for mulberry fibers. This has been confirmed for other fibers in the laboratories of The Institute of Paper Chemistry.

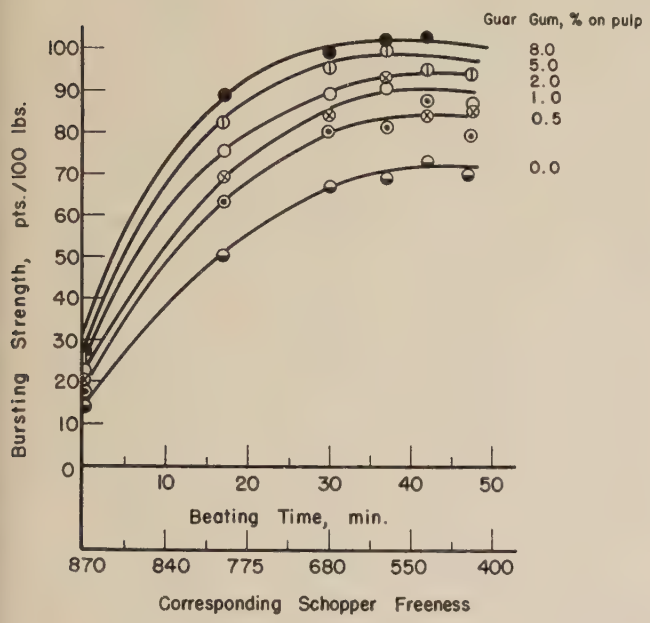



*Fig. 4. The effect of guar gum on the bursting strength of coniferous sulphite pulp handsheets*

Musser and Engel (*17*) investigated the effect of a number of materials on the beating rate of a cotton pulp. Soluble starch, sucrose, psyllium seed mucilage, apple pectin, flaxseed mucilage, methylcellulose, and formaldehyde all increased the beating rate, whereas gelatin appeared to inhibit the beating action. Edge (*18*) has confirmed the effects of methylcellulose on sheet-strength properties and has shown that similar results can be obtained with carboxymethylcellulose derivatives.

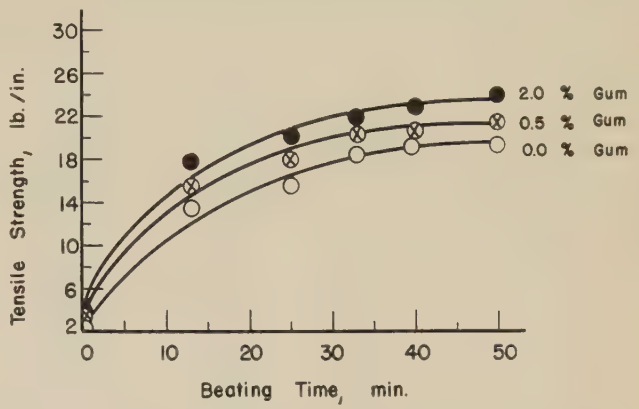



*Fig. 5. The effect of beating and locust bean gum on the tensile strength of coniferous sulphite pulp handsheets*

Horsey (*19*) has shown that 5% of a carboxymethylcellulose which has been precipitated by means of alum will give increases in wet and dry tensile strengths, porosity, and opacity.

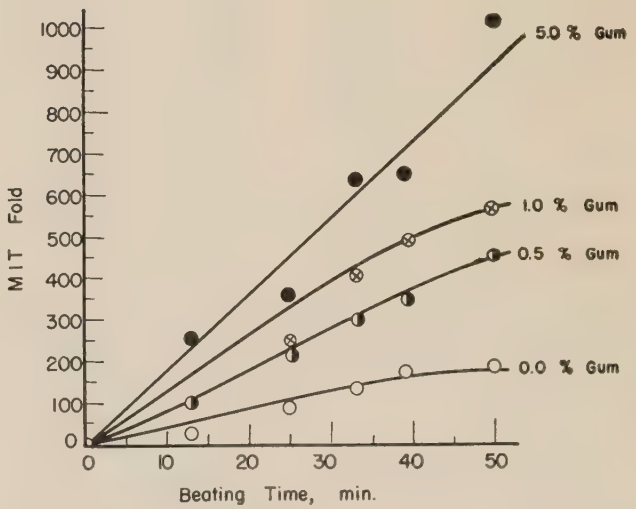



*Fig. 6. The effect of beating and locust bean gum on the folding endurance*

## THE EFFECTS OF LOCUST BEAN GUM ON THE PAPERMAKING PROPERTIES OF CELLULOSE FIBERS

Shortly before the beginning of World War II, workers at The Institute of Paper Chemistry found that locust bean gum possessed many of the desirable properties

necessary to chemically "hydrate" cellulose fibers. It appears that gums of this type are physically adsorbed from aqueous solution by cellulose fibers. Each fiber thereby becomes coated with a film of highly swollen mucilage which gives the pulp many of the same characteristics as mechanical beating. It has been shown that the addition of such a small quantity of gum as 0.1% based on the fiber weight (2.0 pounds per ton of fiber) will give appreciable improvements in both sheet-formation quality and strength properties. Larger quantities of the gum are found to give proportionately larger improvements in these desirable properties.

lishment of a large-scale program of research at The Institute of Paper Chemistry on possible domestic sources of similar gums. The study of the development of guar gum, a mannogalactan very similar in physical properties to locust bean gum, has been published (*21*).

Guar gum is not available in commercial quantities at the present time. Locust bean gum is again being imported to the United States in fairly large quantities and papermaking grades can be obtained for about 25 cents per pound.

**Table I. The Effects of Locust Bean Gum on the Hand**

| *Beating time, min.* | *Locust bean gum added (based on pulp), %* | *Schopper-Riegler freeness of furnish, cc.* | *Basis weight (25 × 40 —500), lb.* | *Caliper, in./1000* | *Apparent density* | *Bursting strength (Mullen)* | |
|---|---|---|---|---|---|---|---|
| | | | | | | *pt.* | *pt./100 lb.* |
| 0 | 0.0 | 870 | 45.6 | 6.0 | 7.6 | 3.8 | 8.3 |
| | 0.5 | 873 | 43.4 | 5.6 | 7.8 | 4.1 | 9.4 |
| | 1.0 | 871 | 41.8 | 5.3 | 7.9 | 4.1 | 9.8 |
| | 2.0 | 877 | 46.9 | 5.8 | 8.1 | 5.5 | 12.0 |
| | 5.0 | 876 | 42.7 | 5.2 | 8.2 | 5.7 | 13.3 |
| | 8.0 | 867 | 47.9 | 5.8 | 8.3 | 7.7 | 16.1 |
| 13 | 0.0 | 820 | 45.0 | 4.2 | 10.7 | 23.2 | 52.0 |
| | 0.5 | 795 | 46.8 | 4.4 | 10.6 | 30.6 | 66.0 |
| | 1.0 | 795 | 44.2 | 4.1 | 10.8 | 30.1 | 68.1 |
| | 2.0 | 753 | 46.4 | 4.2 | 11.0 | 35.6 | 77.0 |
| | 5.0 | 777 | 45.1 | 4.1 | 11.0 | 38.1 | 84.1 |
| | 8.0 | 742 | 45.3 | 4.2 | 10.8 | 34.7 | 77.0 |
| 25 | 0.0 | 710 | 44.4 | 4.0 | 11.1 | 28.9 | 65.1 |
| | 0.5 | 692 | 42.8 | 3.9 | 11.0 | 35.9 | 84.0 |
| | 1.0 | 639 | 45.1 | 4.0 | 11.3 | 38.4 | 85.1 |
| | 2.0 | 640 | 44.8 | 4.0 | 11.2 | 38.4 | 86.0 |
| | 5.0 | 600 | 44.5 | 4.0 | 11.2 | 39.3 | 88.3 |
| | 8.0 | 582 | 44.4 | 4.0 | 11.1 | 41.5 | 93.0 |
| 33 | 0.0 | 600 | 45.3 | 4.0 | 11.3 | 31.0 | 68.0 |
| | 0.5 | 540 | 43.4 | 3.9 | 11.1 | 38.4 | 88.0 |
| | 1.0 | 490 | 44.4 | 3.9 | 11.4 | 41.6 | 94.0 |
| | 2.0 | 445 | 43.6 | 3.8 | 11.5 | 40.7 | 93.3 |
| | 5.0 | 437 | 43.8 | 3.8 | 11.5 | 43.2 | 99.0 |
| | 8.0 | 390 | 44.3 | 3.9 | 11.4 | 46.7 | 105.0 |
| 39 | 0.0 | 500 | 44.2 | 3.8 | 11.6 | 30.3 | 69.0 |
| | 0.5 | 440 | 42.2 | 3.6 | 11.7 | 34.9 | 83.0 |
| | 1.0 | 400 | 43.1 | 3.6 | 12.0 | 41.3 | 96.0 |
| | 2.0 | 352 | 44.4 | 3.5 | 12.7 | 41.6 | 94.0 |
| | 5.0 | 330 | 44.1 | 3.8 | 11.6 | 45.2 | 102.0 |
| | 8.0 | 302 | 44.6 | 3.7 | 12.1 | 44.9 | 101.0 |
| 50 | 0.0 | 400 | 42.1 | 3.5 | 12.0 | 31.0 | 74.0 |
| | 0.5 | 343 | 42.5 | 3.3 | 12.9 | 37.6 | 88.0 |
| | 1.0 | 286 | 42.9 | 3.4 | 12.6 | 39.8 | 93.0 |
| | 2.0 | 284 | 44.1 | 3.5 | 12.6 | 44.6 | 101.0 |
| | 5.0 | 227 | 44.3 | 3.4 | 13.0 | 47.4 | 107.0 |
| | 8.0 | 210 | 43.9 | 3.4 | 12.9 | 45.8 | 104.0 |

### *Gel Preparation*

One of the most characteristic properties of locust bean and similar gums is their ability to form a water-insoluble gel when an aqueous dispersion of the gum is treated with a small quantity of a soluble borate. Smith (*20*) applied this property to papermaking by treating the pulp with small amounts of locust bean gum dispersions and, subsequently, treating the formed sheet with a dilute borax solution. This procedure results in a sheet of wet-strength paper. This type of wet strength is particularly desirable in paper towels and certain tissues. Moreover, the recovery and repulping of waste papers containing locust bean gum and borax present no technical problems.

With the development of World War II, the supplies of locust bean gum obtained from France, Italy, Spain, and North Africa were cut off. This led to the estab-

### *Experimental Procedure*

The following experiments will serve to illustrate the effects of such gums on the papermaking properties of cellulose fibers.

The pulps in these experiments were beaten in a Valley laboratory beater at a consistency of 1.5%. The locust bean gum was cooked in water at a concentration of 0.5% at 85°C. for 10 minutes and the required quantity of gum solution was added to the beaten pulp at 1.5% consistency with vigorous stirring. After 5 minutes of mixing, the furnish was diluted to 0.5% consistency and used to prepare handsheets on a Valley sheet mold. All sheets were heat-dried on blotters for 7 minutes at a temperature of 105° C.

### *Effect of Locust Bean Gum on Bursting Strength*

The effect of locust bean gum on the bursting strength of coniferous sulphite pulp handsheets is shown by the

data in Table I and Fig. 2. One-half per cent of locust bean gum (based on the weight of the pulp) increased the bursting strength of a pulp beaten for 15 minutes to that of a pulp beaten for 50 minutes. This represents a saving of 70% of the beating time and an increase in bursting strength of 32% over the original pulp. Similarly, 1 and 5% additions of locust bean gum gave 40 and 64% increases in bursting strength, respectively. It will be noted that when the gum is added to an unbeaten pulp, very little strength improvement is realized. It appears that it is first necessary to roughen the surface of the celluiose fibers and thereby increase the surface area in order that the gum can be adsorbed in sufficient amounts to chemically hydrate the fibers.

**sheet Properties of a Coniferous Bleached Sulphite Pulp**

| *Elmendorf tear* g./sheet | *Tear factor* | *M.I.T. fold* | *Gurley porosity, sec./100 cc.* | *Schopper tensile, lb./in.* | *Drain time, sec.* | *B. & L. opacity, %* | *Hygro-expansivity, %* |
|---|---|---|---|---|---|---|---|
| 41 | 0.90 | 0 | 0 | 2.3 | 1.6 | 75.5 | 0.117 |
| 52 | 1.20 | 0 | 0 | 3.2 | 1.6 | 76.5 | 0.120 |
| 52 | 1.24 | 0 | 0 | 3.1 | 1.5 | 74.5 | 0.119 |
| 63 | 1.34 | 0 | 0 | 3.8 | 1.6 | 75.0 | 0.122 |
| 65 | 1.52 | 0 | 0 | 3.9 | 1.6 | 75.0 | 0.114 |
| 79 | 1.65 | 2 | 0 | 4.6 | 1.7 | 76.5 | 0.113 |
| 62 | 1.38 | 27 | 10 | 13.6 | 1.7 | 73.5 | 0.116 |
| 61 | 1.30 | 98 | 11 | 15.5 | 1.8 | 71.5 | 0.115 |
| 46 | 1.04 | 102 | 11 | 16.9 | 1.8 | 71.0 | 0.115 |
| 48 | 1.03 | 168 | 11 | 17.9 | 1.9 | 70.0 | 0.124 |
| 44 | 0.98 | 254 | 12 | 18.2 | 1.8 | 69.5 | 0.119 |
| 44 | 0.97 | 238 | 15 | 18.7 | 1.8 | 70.0 | 0.123 |
| 52 | 1.17 | 84 | 28 | 15.7 | 2.1 | 69.5 | 0.127 |
| 38 | 0.89 | 215 | 34 | 17.9 | 2.2 | 67.0 | 0.126 |
| 41 | 0.91 | 244 | 35 | 19.2 | 2.3 | 69.5 | 0.129 |
| 41 | 0.92 | 278 | 36 | 20.1 | 2.4 | 68.5 | 0.126 |
| 39 | 0.88 | 358 | 45 | 21.3 | 2.4 | 67.5 | 0.134 |
| 38 | 0.86 | 383 | 38 | 19.7 | 2.5 | 67.0 | 0.140 |
| 43 | 0.95 | 127 | 181 | 19.2 | 4.4 | 69.0 | 0.142 |
| 36 | 0.83 | 280 | 188 | 20.6 | 4.7 | 65.0 | 0.150 |
| 39 | 0.88 | 358 | 199 | 21.7 | 4.8 | 66.0 | 0.146 |
| 33 | 0.76 | 472 | 219 | 20.8 | 5.0 | 64.5 | 0.144 |
| 33 | 0.75 | 603 | 291 | 23.1 | 5.4 | 63.0 | 0.139 |
| 33 | 0.74 | 677 | 370 | 22.6 | 5.6 | 63.0 | 0.154 |
| 38 | 0.86 | 171 | 451 | 18.6 | 7.6 | 66.5 | 0.143 |
| 31 | 0.73 | 344 | 457 | 20.2 | 8.6 | 64.5 | 0.151 |
| 31 | 0.72 | 494 | 474 | 22.1 | 9.1 | 64.5 | 0.135 |
| 31 | 0.70 | 467 | 637 | 22.0 | 11.9 | 63.5 | 0.150 |
| 29 | 0.66 | 633 | 865 | 24.7 | 12.1 | 59.0 | 0.147 |
| 31 | 0.70 | 594 | 1030 | 24.3 | 13.9 | 61.5 | 0.162 |
| 31 | 0.74 | 180 | 1886 | 19.3 | 23.3 | 62.0 | 0.157 |
| 30 | 0.71 | 448 | 3094 | 21.7 | 22.0 | 60.5 | 0.148 |
| 29 | 0.68 | 562 | 3390 | 22.9 | 24.4 | 60.5 | 0.160 |
| 29 | 0.66 | 673 | 4660 | 24.5 | 27.0 | 59.5 | 0.146 |
| 29 | 0.65 | 1010 | 5110 | 25.2 | 32.0 | 57.5 | 0.158 |
| 26 | 0.59 | 938 | 7350 | 24.2 | 33.0 | 56.0 | 0.168 |

### *Effect on Tearing Strength*

The effect of 1% locust bean gum on the tearing strength of the same sulphite pulp handsheets is shown in Fig. 3. It is characteristic for the tear factor to increase sharply during the initial stages of beating. A maximum is soon reached, and thereafter the tear factor steadily decreases. The tear test is a measure of the work necessary to pull fibers out of the sheet. This work increases at first and then decreases when the fibers become better bonded and break off instead of being pulled out. The addition of a gum which provides better bonding between fibers also produces a tear factor-beating time curve similar to that for mechanical beating. However, with some pulps it has been found possible to increase the bursting strength sufficiently in that region of the beating curve where simultaneous increases in tear and burst are obtained.

### *Effect of Guar on Bursting Strength*

Figure 4 illustrates the effect of various percentages of guar gum on the bursting strength of coniferous sulphite pulp handsheets. Again it is noted that large strength increases are produced with small additions of gum. One-half per cent of the gum (10 pounds per ton of fiber) is sufficient to effect a 50% saving in beating time. Greater amounts of gum produce proportionately greater savings in beating time. The addition of quantities of gum beyond 5 to 8% does not give sufficient added strength improvements to warrant their use.

### *Effect on Tensile Strength*

The tensile-strength data plotted in Fig. 5 indicate pronounced improvements in this property resulting from the addition of locust bean gum. Thus, 2% of the gum (based on the dry weight of a pulp beaten for 20 minutes) gave a 33% increase in tensile strength thereby producing tensile strengths equal to those of sheets prepared from pulps beaten 40 to 50 minutes. A similar beneficial effect of gum addition on folding endurance is illustrated in Fig. 6.

## THE EFFECT OF LOCUST BEAN GUM ON THE STRUCTURAL AND OPTICAL PROPERTIES OF CONIFEROUS BLEACHED SULPHITE HANDSHEETS

It was stated earlier that a chemical hydrating agent

should permit the manufacture of papers which are less dense and more porous, and which can be formed at higher machine speeds. The possibilities of accomplishing these desirable conditions are illustrated in Fig. 7 to 11.

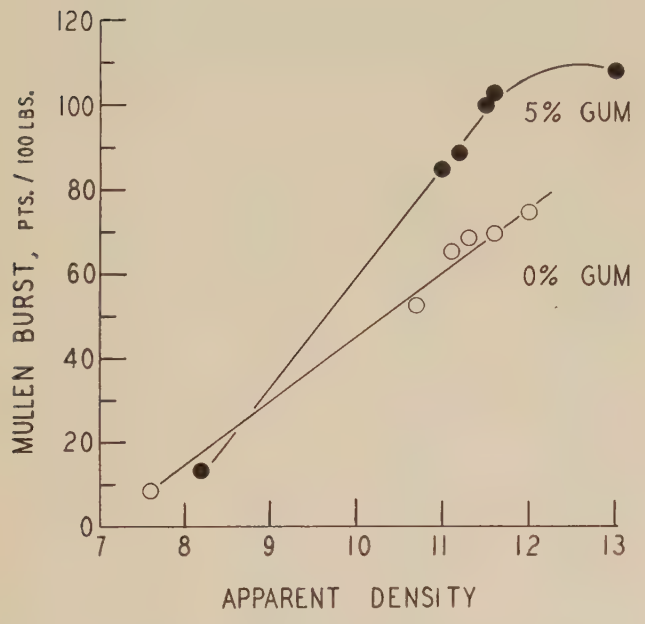



*Fig. 7. The effect of locust bean gum upon the relationship between apparent density and bursting strength of coniferous sulphite pulp handsheets*

### *Effect on Bursting Strength-Density*

The effect of the addition of 5% of locust bean gum upon the relationship between bursting strength and apparent density is shown in Fig. 7. The curves indicate that the bursting-strength properties of sheets having an apparent density of 12 may be equalled at an apparent density of 10.5 by the addition of 5% of locust bean gum to a less highly beaten pulp. This should provide a sheet having better printing properties and with less tendency to curl and cockle.

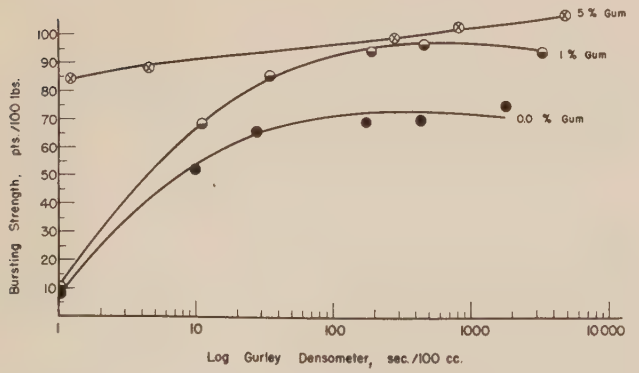



*Fig. 8. The variation of bursting strength and sheet porosity at various concentrations of locust bean gum*

### *Effect on Bursting Strength-Porosity*

Figure 8 shows the effects of locust bean gum upon the bursting strength-Gurley Densometer relationship. This graph indicates that papers of high porosity and high strength can be produced by decreasing mechanical beating and adding chemical hydration to obtain the desired strength. This same effect has been observed on unbleached kraft pulps and should prove interesting to those manufacturing multiwall bags.

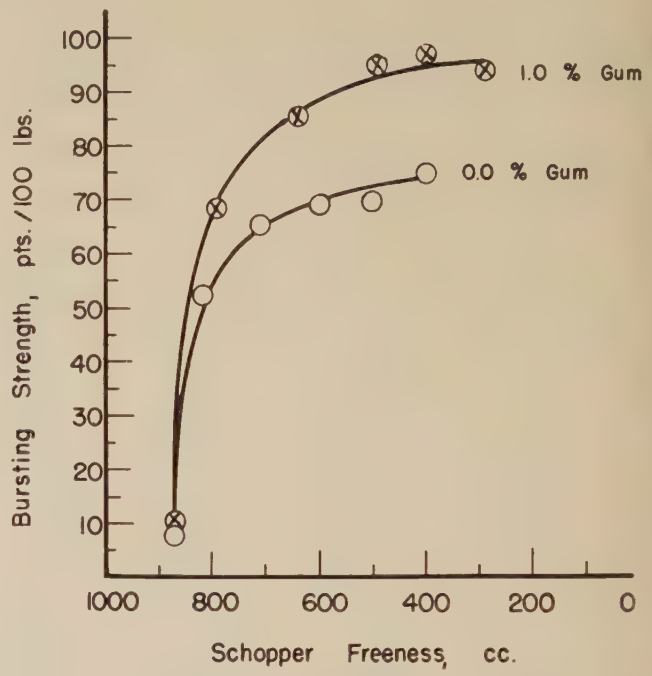



*Fig. 9. The effect of locust bean gum upon the bursting strength-freeness relationship*

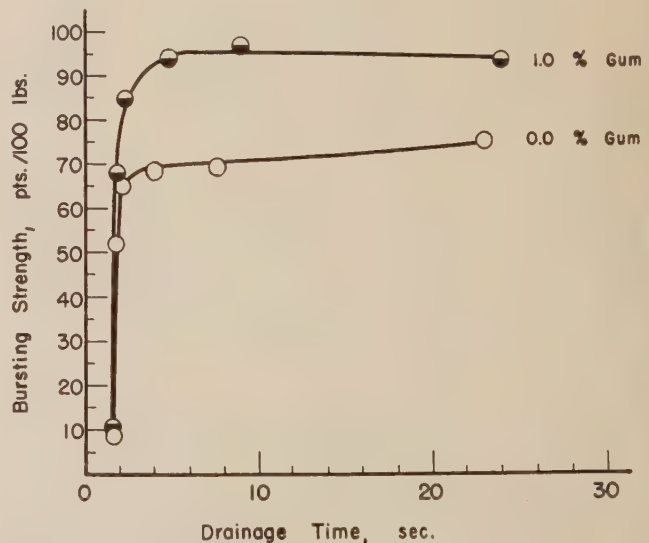



*Fig. 10. Variation of drainage time and bursting strength with locust bean gum*

### *Effect on Drainage Rate*

It has been stated that chemical hydration should

permit higher machine speeds because of faster drainage on the wire and better pulp deflocculation. Figure 9, which concerns the bursting strength-Schopper freeness relationship, illustrates the possibilities of accomplishing this result. It is shown that a furnish prepared from a lightly beaten pulp with 1% locust bean gum has a freeness of 800 ml. and a bursting strength equal to that of a mechanically beaten pulp having a freeness of 400 ml. The considerably improved drainage rate is emphasized in Fig. 10 which shows the relationship between bursting strength and the time necessary for drainage in the sheet mold to form the sheet. Paper-mill experience has shown that the addition of 0.5 to 1.0% of a mannogalactan gum to a practically unbeaten kraft furnish affords a 10% increase in machine speed with improved sheet properties from the standpoints of strength and increased porosity.

**Table II. The Effects of Guar Gum on the Properties of Douglas-Fir Kraft-Pulp Handsheets**

| *Beating time, min.* | *Schopper-Riegler freeness, cc.* | *Guar gum added (based on pulp), %* | *Basis weight (25 × 40 —500), lb.* | *Caliper, in.* | *Bursting strength (Mullen)* | | *M.I.T. fold* | *Elmendorf Tear* | | *Schopper tensile, lb./in.* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | *pt.* | *pt./ 100 lb.* | | *g./ sheet* | *Tear factor* | |
| 5 | 870 | 0.0 | 50.6 | 0.0075 | 12.7 | 25 | 7 | 111 | 2.19 | 7.9 |
| | | 0.5 | 49.7 | 0.0069 | 17.8 | 36 | 19 | 127 | 2.56 | 9.5 |
| | | 1.0 | 49.0 | 0.0070 | 19.5 | 40 | 19 | 129 | 2.63 | 10.3 |
| | | 2.0 | 47.0 | 0.0069 | 19.6 | 42 | 26 | 138 | 2.94 | 10.4 |
| 30 | 800 | 0.0 | 48.5 | 0.0053 | 39.7 | 82 | 539 | 127 | 2.60 | 20.3 |
| | | 0.5 | 47.8 | 0.0054 | 50.2 | 105 | 726 | 97 | 2.03 | 21.0 |
| | | 1.0 | 47.9 | 0.0053 | 52.3 | 109 | 712 | 102 | 2.13 | 22.1 |
| | | 2.0 | 48.4 | 0.0053 | 52.6 | 109 | 732 | 101 | 2.09 | 23.0 |
| 72 | 650 | 0.0 | 48.0 | 0.0050 | 50.4 | 105 | 970 | 101 | 2.10 | 23.8 |
| | | 0.5 | 46.8 | 0.0048 | 56.2 | 120 | 1020 | 89 | 1.90 | 25.4 |
| | | 1.0 | 46.0 | 0.0048 | 57.5 | 125 | 1100 | 83 | 1.81 | 26.8 |
| | | 2.0 | 46.5 | 0.0047 | 59.5 | 128 | 1150 | 82 | 1.76 | 27.5 |
| 120 | 480 | 0.0 | 47.3 | 0.0046 | 48.5 | 103 | 1100 | 97 | 2.05 | 24.2 |
| | | 0.5 | 46.9 | 0.0045 | 57.1 | 122 | 967 | 87 | 1.86 | 27.5 |
| | | 1.0 | 46.3 | 0.0044 | 61.0 | 132 | 1140 | 81 | 1.75 | 27.5 |
| | | 2.0 | 48.0 | 0.0047 | 63.5 | 132 | 1060 | 83 | 1.73 | 27.4 |

**Table III. Comparison of Guar Gum, Locust Bean Gum, and Borax-Treated Potato Starch as Beater Additives**

| | *Dry, 1%* | *Guar gum (cooked), 1%* | *Locust bean gum (cooked), 1%* | *Potato starch (borax-treated), 5%* |
|---|---|---|---|---|
| Bursting strength, pt./ 100 lb. | 14.4 | 15.0 | 16.8 | 14.2 |
| Folding endurance (Schopper) | | | | |
| Machine direction | 190 | 205 | 260 | 200 |
| Cross direction | 48 | 42 | 49 | 64 |
| Schopper-Riegler freeness, cc. | 610 | 610 | 630 | 590 |

*Note:* Basis weight, 9 lb. (17 × 22—500); furnish, 50% rag, 50% bleached kraft.

### *Effect on Dimensional Stability*

Papers of lower density, higher porosity, and better formation might be expected to show lower changes in external dimensions with changing relative humidity because of a greater opportunity for expansion and contraction of the fibers within the voids of the sheet. This effect is shown in Fig. 11 where it is indicated that papers of higher bursting strength and lower hygroexpansivity may be made by decreasing mechanical refining and adding locust bean gum.

### *Effect on Opacity*

Figure 12 shows that papers of higher opacity and higher bursting strength can be prepared by adding locust bean gum to a less highly refined pulp. Thus, on the basis of a desired bursting strength of 74 points per 100 pounds, mechanical hydration gives a sheet of 62%

**Table IV. Effects of the Jordan Refiner, Cornstarch, and Locust Bean Gum on the Properties of a Sulphite-Soda Paper made on an Experimental Paper Machine**

| *Reel No.* | *Condition of Jordan* | *Additive present (based on fiber), %* | *Bursting strength, pt./ 100 lb.* | *Apparent density* | *M.I.T. fold* | | *Elmendorf tear* | | *Gurley porosity, sec./ 100 cc.* | *TAPPI size* | | *Thwing formation no.* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | *M.* | *C.* | *M.* | *C.* | | *W.* | *F.* | |
| 5 | on | Starch, 3 | 59.7 | 11.8 | 113 | 53 | 68 | 76 | 59 | 53 | 56 | 42.3 |
| 6 | on | Starch, 3 | 60.0 | 11.8 | 132 | 48 | 68 | 78 | 56 | 57 | 60 | 42.4 |
| 7 | on | None | 53.2 | 11.1 | 92 | 30 | 74 | 90 | 30 | 54 | 56 | 37.9 |
| 7M | off | None | 39.9 | 9.9 | 35 | 12 | 100 | 109 | 10 | 56 | 53 | 31.3 |
| 8 | off | None | 39.3 | 9.9 | 24 | 7 | 100 | 108 | 7 | 51 | 54 | 33.2 |
| 8M | off | LBG,[a] 1 | 53.3 | 10.2 | 103 | 33 | 74 | 82 | 10 | 50 | 51 | 36.5 |
| 9 | off | LBG,[a] 1 | 63.0 | 10.4 | 124 | 52 | 72 | 82 | 9 | 53 | 50 | 36.2 |
| 9M | off | LBG,[a] 1 | 62.0 | 10.3 | 141 | 49 | 75 | 81 | 10 | 49 | 52 | 38.9 |
| 10 | off | LBG,[a] 1 | 60.8 | 10.4 | 118 | 43 | 68 | 74 | 7 | 41 | 43 | 39.0 |
| 11 | off | LBG,[a] 3 | 64.2 | 10.1 | 158 | 47 | 68 | 72 | 7 | 37 | 42 | 44.6 |

[a] LBG is locust bean gum.
*Note:* Basis weight, 50 lb. (24 × 36 –500); furnish: 75% bleached sulphite, 25% bleached soda, 5.5% ash (clay), 3% rosin, 4% alum, pH = 4.8.

opacity, whereas a less highly refined pulp containing 1% locust bean gum yields a sheet having a 70% opacity.

Similar improvements in strength properties have been observed with kraft pulps. Table II presents data

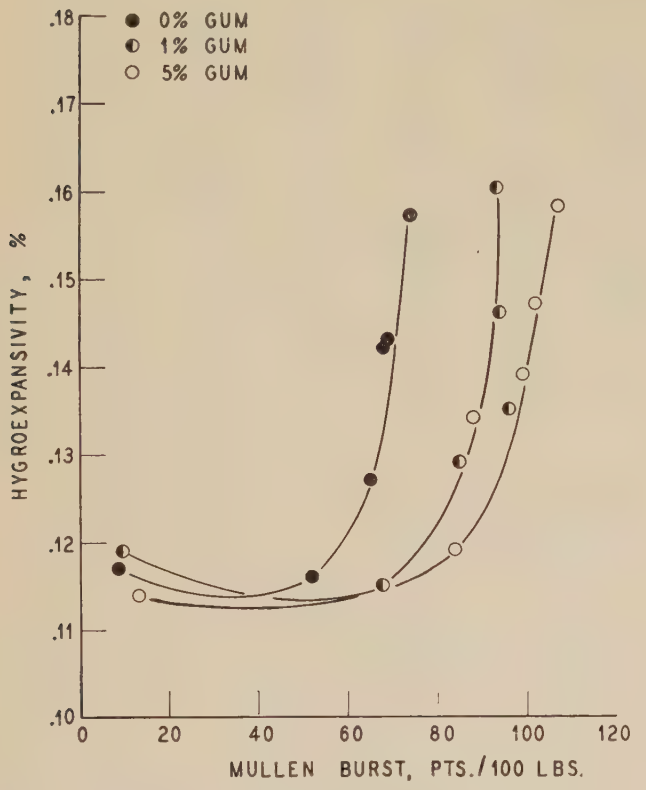



*Fig. 11. The effect of locust bean gum upon the relationship between hygroexpansivity and bursting strength*

illustrating the effects of guar gum on the properties of a Douglas-fir kraft pulp. It is noted that marked improvements occur in the bursting and tensile strengths and the folding endurance. It appears from the data that this pulp has a low capacity for sorbing the gum, because 2% of guar gum based on the pulp does not give much greater improvements than 0.5 and 1%.

### *Mill-Scale Comparisons*

The foregoing data were obtained from laboratory handsheets. A mill-scale comparison of guar gum, locust bean gum, and a borax-treated potato starch is shown in Table III. These data show that guar and locust bean gums do not differ greatly in their effects on strength properties, and that they are markedly superior to starch.

Although many mill trials of locust bean gum and other beater additives have been made, the majority of these trials have been approached cautiously when considered from the standpoint of changing the refining operation; paper mills are reluctant to make paper that cannot be sold. One of the major difficulties in evaluating the benefits of beater or wet-end additives lies in obtaining a representative control sheet with which a comparison can be made.

An opportunity was recently presented in the academic program at The Institute of Paper Chemistry to determine some of the effects of locust bean gum on a sulphite-soda furnish formed on a 38-inch experimental paper machine. This experiment was designed to determine the extent to which jordan refining could be replaced by locust bean gum. The furnish was composed of 75% bleached spruce sulphite, 25% bleached soda, 5% clay, 3% cooked corn starch, 3% rosin size, and 4% alum at a final pH of 5.5. The starch and locust bean gum were cooked and added at the jordan outlet. The pulp in the machine chest was maintained at a low level in order that rapid changes could be made. The sheet had a basis weight of 50 pounds (24 × 36—500). The data which are presented in Table IV show the expected decreases in apparent density, bursting strength, folding endurance, and Thwing formation, and increases in porosity and tearing resistance when the starch was withheld and the jordan was turned off. It is clearly apparent, however, that 1% of locust bean gum (based upon the fiber weight) restored the strength properties to their former levels with the advantage of a

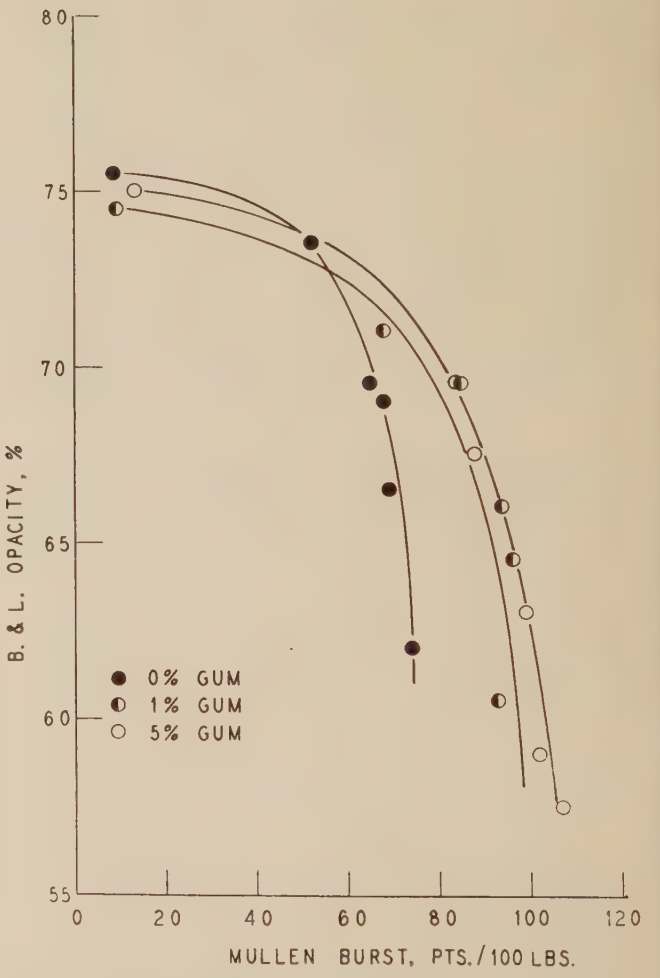



*Fig. 12. The effect of locust bean gum upon the relationship between opacity and bursting strength*

somewhat lower apparent density and considerably greater porosity. Moreover, the formation value returned to normal upon addition of the gum. Thus, it appears that 1% of locust bean gum accomplished the

results previously provided by the jordan and 3% of cooked cornstarch.

### THE USE OF LOCUST BEAN GUM IN A MIXED HARDWOOD-SOFTWOOD PULP FURNISH

One of the serious problems facing the paper industry today is the decreasing supply of desirable coniferous pulps. This type of pulp is important because of its long fiber length and strength-producing qualities. It is becoming increasingly necessary in many grades of paper to use greater percentages of short fibered hardwood pulps—which, in general, do not respond very well to beating and which produce a sheet having very little strength. The differences between these pulps are shown in Table V and Fig. 13. Unfortunately, the hardwood pulp used for these experiments does not respond very well to the action of locust bean gum. However, the large response of the coniferous pulps to the action of the gum enables the papermaker to mix larger quantities of the hardwood pulp with the softwood pulp and, by means of the gum, maintain the same strength properties. This is illustrated in Fig. 14. These data show, for example, that the percentage of hardwood pulp in a softwood-hardwood mixture can be increased from 10 to 45% and the strength held constant by the addition of 3% locust bean gum (based on the weight of the total furnish).

**Table V. Properties of Handsheets made from Mixtures of Coniferous and Deciduous Sulphite Pulps and Locust Bean Gum**

| Compositions of furnish (based on total pulp), % | | | Schopper-Riegler freeness of furnish, cc. | Basis weight (25 × 40 —500), lb. | Apparent density | Bursting strength | | Elmendorf tear | | M.I.T. fold | Schopper tensile, lb./in |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Coniferous sulphite | Deciduous Sulphite | Gum added, % | | | | pt. | pt./100 lb. | g./sheet | Tear factor | | |
| 100 | 0 | 0.0 | 750 | 45.2 | 10.3 | 25.5 | 56 | 60 | 1.33 | 42 | 14.3 |
| | | 0.5 | 685 | 44.5 | 8.2 | 27.9 | 63 | 71 | 1.60 | 80 | 16.7 |
| | | 1.0 | 639 | 43.1 | 10.8 | 34.3 | 80 | 44 | 1.02 | 188 | 16.8 |
| | | 3.0 | 568 | 44.1 | 10.8 | 37.6 | 85 | 45 | 1.02 | 167 | 18.5 |
| | | 5.0 | 638 | 45.2 | 10.8 | 40.8 | 90 | 51 | 1.13 | 253 | 18.2 |
| | | 10.0 | 548 | 44.3 | 10.8 | 39.8 | 90 | 41 | 0.93 | 392 | 18.5 |
| 75 | 25 | 0.0 | 747 | 44.0 | 9.6 | 18.3 | 42 | 58 | 1.32 | 13 | 10.4 |
| | | 0.5 | 692 | 43.3 | 10.1 | 22.2 | 51 | 48 | 1.11 | 34 | 12.4 |
| | | 1.0 | 672 | 42.2 | 10.0 | 22.4 | 53 | 42 | 1.00 | 31 | 12.6 |
| | | 3.0 | 608 | 43.3 | 10.1 | 25.7 | 59 | 44 | 1.02 | 50 | 13.5 |
| | | 5.0 | 616 | 42.9 | 10.2 | 28.9 | 67 | 42 | 0.98 | 56 | 13.1 |
| | | 10.0 | 625 | 43.9 | 10.5 | 28.8 | 66 | 46 | 1.05 | 67 | 15.2 |
| 50 | 50 | 0.0 | 755 | 43.7 | 8.9 | 11.0 | 25 | 45 | 1.03 | 4 | 7.5 |
| | | 0.5 | 704 | 42.9 | 9.1 | 15.0 | 35 | 40 | 0.93 | 8 | 9.5 |
| | | 1.0 | 675 | 44.0 | 9.2 | 16.2 | 37 | 43 | 0.98 | 11 | 9.9 |
| | | 3.0 | 593 | 43.8 | 10.2 | 19.1 | 44 | 41 | 0.94 | 12 | 10.6 |
| | | 5.0 | 685 | 43.7 | 9.9 | 19.5 | 45 | 41 | 0.94 | 12 | 9.9 |
| | | 10.0 | 600 | 43.7 | 9.7 | 20.8 | 48 | 38 | 0.87 | 17 | 11.0 |
| 25 | 75 | 0.0 | 767 | 42.8 | 8.7 | 8.0 | 19 | 28 | 0.65 | 1 | 4.8 |
| | | 0.5 | 697 | 43.7 | 8.7 | 9.2 | 21 | 30 | 0.69 | 2 | 5.8 |
| | | 1.0 | 722 | 43.7 | 8.9 | 9.8 | 22 | 28 | 0.64 | 2 | 6.1 |
| | | 3.0 | 675 | 43.7 | 8.7 | 10.0 | 23 | 31 | 0.71 | 3 | 6.0 |
| | | 5.0 | 699 | 43.1 | 8.8 | 9.6 | 22 | 31 | 0.72 | 2 | 5.8 |
| | | 10.0 | 621 | 44.5 | 8.9 | 11.5 | 26 | 32 | 0.72 | 2 | 6.4 |
| 0 | 100 | 0.0 | 770 | 42.8 | 7.9 | 8.0 | 19 | 9 | 0.21 | 0 | 2.2 |
| | | 0.5 | 680 | 43.0 | 8.3 | 8.1 | 19 | 9 | 0.21 | 0 | 2.6 |
| | | 1.0 | 730 | 41.7 | 8.2 | 8.2 | 20 | 9 | 0.22 | 0 | 2.7 |
| | | 3.0 | 663 | 42.8 | 8.4 | 8.1 | 19 | 12 | 0.28 | 0 | 3.3 |
| | | 5.0 | 680 | 41.5 | 8.1 | 8.4 | 20 | 11 | 0.27 | 0 | 3.1 |
| | | 10.0 | 619 | 43.1 | 8.3 | 8.3 | 19 | 12 | 0.28 | 0 | 3.6 |

### EFFECT OF MANNOGALACTAN GUMS ON THE FORMATION QUALITY OF PAPER

It was mentioned earlier that certain gums have been used to improve fiber dispersion and sheet-formation quality. It was found during the early stages of the study of locust bean gum that it also possessed marked fiber-dispersing ability. Whereas the oriental mucilages are added in rather large percentages (often the equivalent of 100%, based on the cellulose fiber solids), locust bean gum was found to maintain the dispersion of fibers at much lower concentrations. It has been noted that considerable differences in this quality exist even among various mannogalactan gums. This is shown in Table VI and Fig. 15. These data should not be accepted as representative of the results to be expected in all commercial operations. A multitude of paper-machine variables have a marked effect on the formation value of the paper being made.

It is believed that the formation-improving properties of these gums is the result of both a negative electrokinetic potential and a hydrophilic layer which is produced on the cellulose fiber when the gum is added to the pulp. Actually, these gums do not disperse cellulose fibers but rather they delay flocculation and entanglement. On this basis, positively charged cations would be expected to reduce the negative charge and thereby decrease the formation-improving quality. Alum, which is used in the manufacture of a great many sized papers, should have this effect. This is shown in Fig. 16 where the formation values of handsheets are plotted against flocculation time; the curves show the effect of various percentages of alum on fibers which contain 0 and 2% concentrations of locust bean gum. It will be noted that the formation values of the handsheets gradually become poorer with increasing flocculation

time, and that increasing quantities of alum are detrimental to the formation qualities of the mucilage. However, it is evident that the addition of 15% of alum

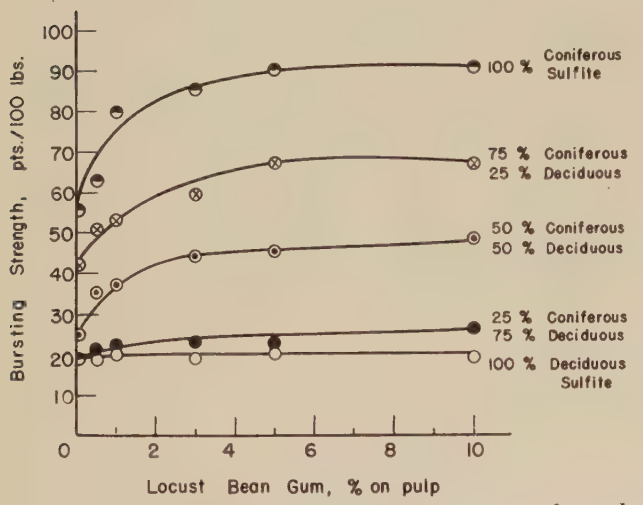



*Fig. 13. The effect of locust bean gum on softwood-hardwood pulp mixtures*

(based on the fiber) did not decrease the formation quality of the mucilage to a point as low as that of the fiber alone. This residual formation-improving quality in the presence of 15% of alum may be attributed to the hydration layer which the gum imparts to the cellulose fibers. In commercial usage, these gums have not al-

**Table VI. Effect of Gums on the Formation Number of Unbeaten Sulphite Pulp Handsheets**

| *Gum* | *Amount of gum added (based on pulp), %* | *Thwing formation No.* |
|---|---|---|
| Blank | 0.0 | 25.3 |
| Guar | 1.0 | 29.2 |
| | 3.0 | 32.8 |
| | 5.0 | 33.2 |
| Flame tree | 1.0 | 32.8 |
| | 3.0 | 34.9 |
| | 5.0 | 38.4 |
| Locust bean | 1.0 | 38.0 |
| | 3.0 | 40.7 |
| | 5.0 | 40.2 |
| Tara | 1.0 | 34.1 |
| | 3.0 | 35.0 |
| | 5.0 | 33.9 |

ways met with complete success in improving the formation quality of the sheet. In general, however, these gums have shown the best results in furnishes containing little or no alum. Figure 17 illustrates the effect of the addition of 2% of guar gum on the flocculation of a long fiber furnish used to produce electrolytic condenser paper. These are transparencies of the actual papers made in a commercial operation.

## FUNDAMENTAL STUDIES ON BEATER ADDITIVES

Judging from the data presented and the remarks made thus far, the impression may be gained that mannogalactan gums are the complete answer to the papermaker's desire of chemical hydration. Actually, the situation is not as simple as it appears from laboratory handsheet data. Whereas many successful mill trials of these gums and similar additives have been made, and a number of paper mills are presently using such gums in regular production, there have been many other mill trials in which the additive apparently functioned poorly or not at all. This situation is not new, however. For example, considerable difference of opinion exists among papermakers with regard to the benefits obtained from cooked starch. Jayne, Tongren, and Jackson (*22*) recently emphasized the confusion which exists because of contradictory results and inconsistent performance of materials used as beater and headbox additives. All this strongly indicates the great need for fundamental information with regard to the physical and chemical properties of such additives and the variables which affect their behavior in the presence of cellulose fibers. Fundamental studies of this type have been hampered by the lack of a sufficiently accurate method for measuring the retention of the additive by the cellulose fiber.

Recently two methods have been investigated which appear to possess the necessary sensitivity for measuring sorption of carbohydrate additives on cellulose by concentration difference. The first method involves the measurement of the viscosity difference before and after sorption, and the second method involves the determination of the difference in carbohydrate concentration before and after sorption by means of Dreywood's anthrone reagent (*23*). Details of these methods will be published soon.

### *Sorption of Methylcellulose*

Working with these techniques, Ellsworth Shriver has recently studied the sorption of methylcellulose by

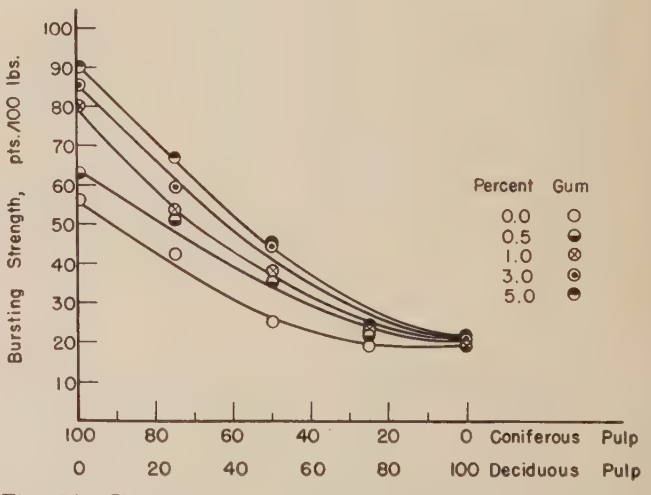



*Fig. 14. Variation of bursting strength of handsheets made of mixtures of hard- and softwood pulps and locust bean gum*

various types of cellulose fibers (*24*). He found that a period of 180 hours was necessary to attain equilibrium sorption on unbeaten pulps at 0.5% consistency when 1% methylcellulose was added. However, for beaten pulps the sorption was 70% complete in 2 hours. Evidence was obtained which clearly indicates that sorption

of methylcellulose by pulp fibers is a function of beating and increases with the degree of pulp treatment. The retention of 400-cp. methylcellulose by well-beaten pulps was found to be about three to four times that for the unbeaten pulp. The data fit moderately well an isotherm of the Langmuir type which reaches a near-saturation value for sorption at 20% methylcellulose (based on the pulp). Considerable difference exists between pulps with regard to sorption at similar degrees of beating. Bleached sulphite pulp had the greatest sorptivity and was followed closely by bleached kraft and unbleached sulphite, but cotton linters and unbleached kraft sorbed much less methylcellulose.

Experiments with four methylcellulose samples varying in molecular weight from 31,000 to 126,000 indicated no significant differences in the extent of sorption by a 770-ml. S.-R. bleached sulphite pulp.

The retention of methylcellulose was found to be irreversible with respect to decreasing concentration under isothermal conditions. However, lowering the temperature resulted in the removal of some methylcellulose from the fiber. On the other hand, increasing the temperature from 25 to 38°C. doubled the retention. Studies of isotherms between 38.0 and 3.3° led to the formation of an hypothesis for the retention of methylcellulose. This hypothesis involves a combination of an endothermic gelation process and an exothermic adsorption process. The heat of retention as determined from the sorption isotherms by means of the Clausius-Clapeyron equation was found to be 21,500 cal. per mole (endothermic). Subtracting this value from the known

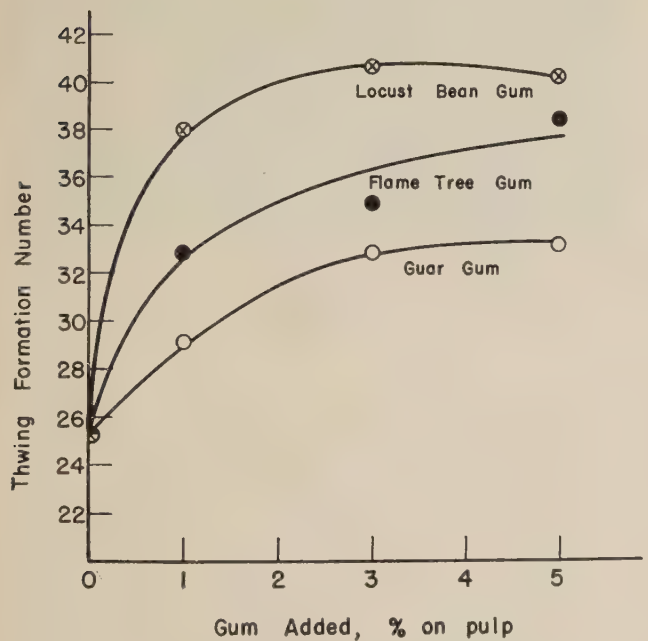



*Fig. 15. The effect of gums on the formation number of unbeaten sulphite pulp handsheets*

heat of gelation (29,700 cal. per mole, endothermic) gave a net heat of adsorption of −8,200 cal. per mole.

The presence of 4% rosin and 6% alum based on the pulp had no effect on the retention of methylcellulose. However, alum concentrations of 60 to 600% on the pulp greatly increased the retention. Gross precipitation was not involved because addition of the same quantity of alum to the methylcellulose caused no coagulation.

These fundamentals should have direct application to paper-mill practice with regard to the point of addition

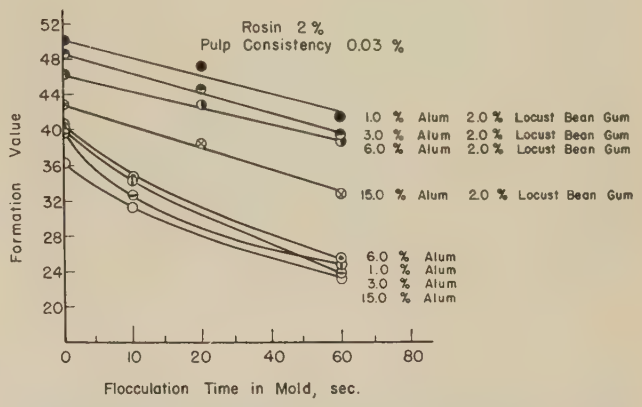

Rosin 2 %
Pulp Consistency 0.03 %
Formation Value
Flocculation Time in Mold, sec.
1.0 % Alum 2.0 % Locust Bean Gum
3.0 % Alum 2.0 % Locust Bean Gum
6.0 % Alum 2.0 % Locust Bean Gum
15.0 % Alum 2.0 % Locust Bean Gum
6.0 % Alum
1.0 % Alum
3.0 % Alum
15.0 % Alum

*Fig. 16. The effect of rosin, alum, and locust bean gum on the formation values of sulphite pulp handsheets made at various flocculation times*

of methylcellulose in the paper-mill system, differences in retention between summer and winter, effects of beating, sizing, etc.

Similar studies on the mannogalactan gums are in progress (*25*). These studies have thus far shown that the adsorption isotherms of locust bean and guar gums are of the Langmuir type, and that the sorption is essentially irreversible.

Light electron microscopic studies have failed to detect the presence of these gums on the fiber surface.

### *Effect of Locust Bean Gum on Bonded Area*

An experiment regarding the effect of locust bean gum on the bonded area of sulphite pulp handsheets is of interest. The data are presented in Table VII. The bonded area measurements were determined by the optical scattering method described by Parsons (*26*).

**Table VII. The Effect of Locust Bean Gum upon the Bonded Area of Coniferous Bleached Sulphite Handsheets**

| *Locust bean gum added (on pulp), %* | *Specific Scattering Coefficients, s × 10³ Butanol-formed sheets*[a] | *Water-formed sheets* | *Difference* | *Bonded area, sq. cm./g.* | *Tensile strength, lb./in.* |
|---|---|---|---|---|---|
| 0 | 71.8 | 35.8 | 36.0 | 5000 | 9.1 |
| 1 | 72.7 | 34.4 | 38.3 | 5150 | 10.1 |
| 3 | 73.6 | 32.7 | 40.9 | 5800 | 11.7 |
| 5 | 74.8 | 32.2 | 42.6 | 6000 | 11.4 |

[a] The average specific surface of the butanol-formed handsheets was 10,450 sq. cm./g.

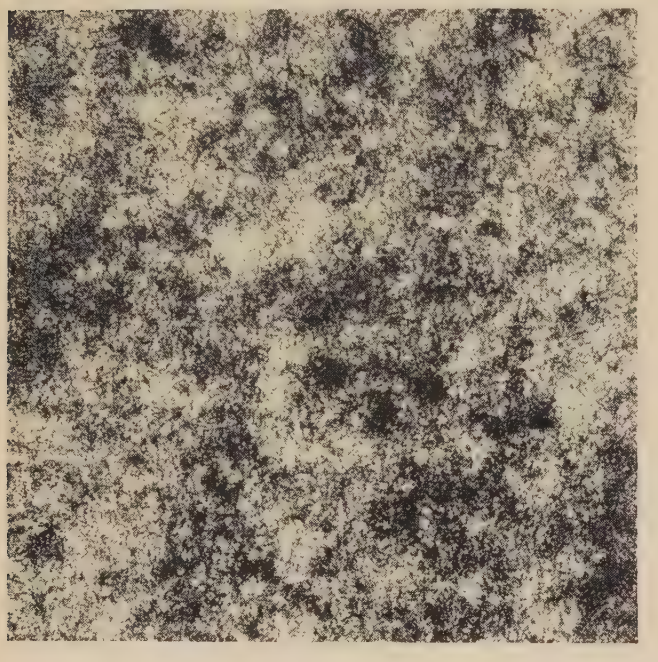
It will be noted that the addition of 1 to 5% of locust bean gum to the sulphite pulp (S.-R. freeness 800 ml.) caused a progressive increase in the bonded area from 5000 to 6000 sq. cm. per gram. The improvement in formation resulting from the addition of locust bean gum is believed responsible for the slight but regular increase in the specific scattering coefficient of the butanol-formed sheets. Although not apparent from the

data, the $s$ values for the water-formed sheets were similarly affected by improvement in formation. It is interesting to note that the increase in bonded area from 5000 to 6000 sq. cm. per gram is approximately proportional to the increase in tensile strength of the water-formed sheets.

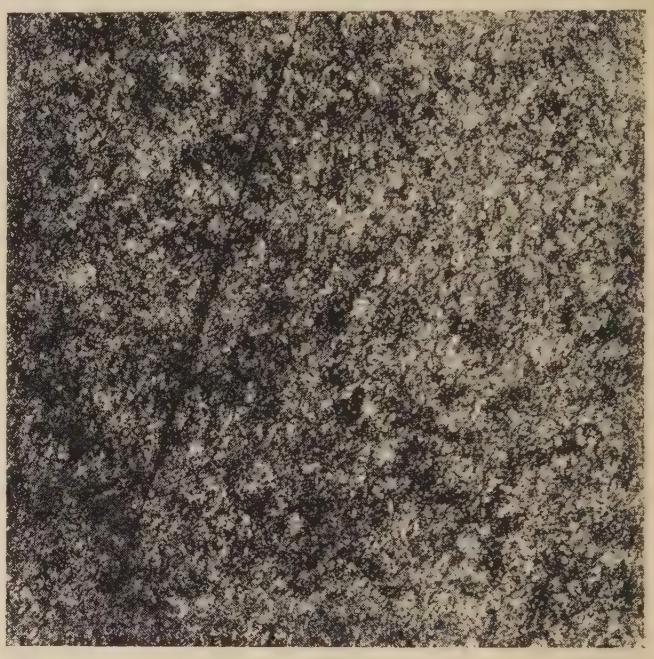
### *Absorption of Gum by Clay*

Other studies have indicated marked adsorption of gums by certain fractions of clays. The presence of such minerals in the fillers used by the paper industry may have some bearing on the decreased benefits of gums added to furnishes containing such fillers. Further work is indicated on the effects of cellulose fines, alumina, and other materials which are present in recirculated white water.

It is believed that further study of these materials and the variables involved will ultimately lead to logical explanations for the inconsistent behavior of these beater additives and to ways of improving their effectiveness. The advantages to be gained by their use will undoubtedly stimulate research in this field.



0% Guar gum



2% Guar gum

***Fig. 17. Effect of 2% guar gum on the flocculation of a long-fiber pulp for condenser paper***

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# The Resin Bonding of Paper Fibers

C. G. LANDES

**This paper is devoted to the progress and problems involved in the use of synthetic resins for the binding of papermaking fibers. The types of resins used and the methods and problems for their incorporation into the furnish are given. The effects on the strength of the sheet are noted. The use of melamine, anionic urea, and cationic urea resins for the production of wet-strength paper and the theories of their bonding actions are presented. The mechanism of binding and the distribution of melamine resin in the sheet has been the object of considerable investigational work, data for which are given in the form of curves and electron photomicrographs. The paper is also a review of the literature, references to which are cited.**

How many times have paper mill men thought of the many new synthetic resins now available and of the possibility of adding, for example, a rubbery type of resin which would improve dry and wet tensile and burst, provide the tearing strength of a textile fabric and the toughness of leather, and enable the use of cheaper pulps and less power for beating—all without difficulties in machine operation or in broke recovery and at a cost not to exceed $10 per ton? Although this objective has not quite been attained it is true that, within the last ten years, the availability of a host of new synthetic resins and elastomers has stimulated tremendous research and development activity in the production and utilization of such materials.

Let us first review the types of resins presently available, and then examine in more detail their properties, applications, and methods of use. Because of the scope of this field, detailed discussion is necessarily limited to selected subjects.

## TYPES OF RESINS

There are many possible ways of classifying the synthetic resins now available to the paper maker, but perhaps the easiest way is to divide them into thermosetting and thermoplastic materials.

### *Thermoplastic Materials*

Although natural rubber latex has been used to some extent in treating paper for many years, the use of synthetic rubber latices and resin emulsions has attracted great interest recently because of the variety of new materials made available since 1940 (*1–7*). Synthetic rubbers being used or tried include butadiene-styrene copolymers (GR-S), butadiene-acrylonitrile copolymers, chlorobutadiene polymers (Neoprene), and several others. Other emulsion polymerized thermoplastics under consideration are polyvinyl acetate, polyvinyl chloride, polyacrylates, polystyrene, and numerous copolymers. These materials are produced with a broad range of properties which permit the treatment of paper in many ways and for many purposes. The treated papers may vary from flexible and tough to rigid and hard.

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Lignin, a thermoplastic of natural origin, is generally used in conjunction with a thermosetting resin such as the phenolic type. Combined with paper such resins are finding increasing uses as rigid laminates (*8–10*).

### *Thermosetting Resins*

Phenolic-type resins are used widely for paper-base laminates, pulp boards and blanks, pulp preforms, and wallboard (*11–16*). Many forms of the resins are available including solutions, varnishes, and powders, either alone or compounded.

Melamine resins are used for laminates—especially for decorative and special industrial uses (*17*). Melamine and other thermosetting resins have also been employed for pulp preforms and other rigid products (*16*). Polyester resins recently have found wide application in the laminating field because of outstanding properties and the fact that very little pressure is required.

Melamine and urea resins have found increasing usage for the manufacture of wet-strength paper and now are considered to be standard raw materials in many paper mills. Certain phenolic resins (*18*, *19*) have been introduced recently for special types of wet-strength paper, as well as for paper-base plastics.

## METHODS OF ADDITION

The general methods of incorporating resins into paper, paperboard, or pulp articles have been described many times, and the problems involved and advantages and disadvantages of each method outlined (*4*, *5*, *20–22*).

For the addition of fairly large proportions of resins to paper, saturation or impregnation procedures have been more widely used to date since they have been the most trouble free. A disadvantage is the additional conversion costs involved. Addition of the resins to the slush stock or pulp (commonly called "beater addition") has been employed successfully to a limited extent, particularly in the case of pulp preforms and thick wet-machine products where formation in a single web is not involved. Latices and resin emulsions have also been precipitated in the stock and run successfully when only small or moderate proportions of resin were added to the sheet.

Many years ago natural rubber latex was recognized as imparting desirable qualities when added to paper, but oxidation and the resultant deterioration of sheet properties presented a serious problem. The operating difficulties in attempting to add the rubber latex at the beater were well described in 1938 by Flint (*23*) as follows: "The accidents encountered—consisted of the clogging of the wire by bits of coagulum, which also stuck to the press rolls while, worst of all, the aggregates resulting from the coarse or nonuniform coagulation of the rubber caused the finished paper to stick to the calenders." These and similar difficulties have a familiar ring even at the present time.

However, because of the continuous pressure for lower

costs, and the availability of many new and interesting synthetic resins and rubbers, both the paper mills and the resin suppliers, as well as independent research groups, have carried out intensive development work on processes for the beater or stock addition of resins to paper and pulp products. Unfortunately, much of this work is not generally available, although some has been published in the technical and patent literature, and resin manufacturers' bulletins. Most such processes are somewhat limited in scope of application, and this is to be expected in view of the divergent nature of the resins and latices available for use.

To illustrate some of the progress that has been made, and also some of the problems involved, a few of the methods developed recently for the beater addition of various types of synthetic polymers are described briefly.

***Neoprene Latex Process (DuPont)***

Amounts up to 50% latex solids are added to slush stock by a controlled flocculation procedure such that the very small particles are deposited in the form of small flocs uniformly attached to the fibers. The method consists in adding to the latex a stabilizing agent (naphthalenesulphonic acid-formaldehyde condensation product) and a sensitizing agent such as alum, with the latex pH controlled on the alkaline side. The latex is then added to the pulp which previously has been blended with a vulcanizing agent and antioxidant. The sensitized latex is coagulated on the pulp by the addition of alum to a pH of about 4.5. Mill trials have demonstrated that the process is practicable, although it was noted that the presence of excessive electrolytes in the process water gave premature precipitation of the latex in some cases.

Walsh and co-workers (*24*) report that use of up to 5% latex solids in the sheet gives good wet-strength properties, together with improved dry tensile and burst, elongation, folding endurance, and sizing. Larger proportions of latex in the sheet produce leatherlike paper having good strength, flexibility, water resistance, cutting, and embossing properties, etc.

***Beater Addition of Phenolic Resins (Snyder)***

The process recently announced by Snyder (*18*, *19*) apparently involves the use of special types of phenolic resins of unknown composition. The resin is diluted with an equal volume of warm water and added to stock slightly on the alkaline side. The resin hydrophobes out on dilution to give a milky emulsion. It is then precipitated on the fiber by rapid addition of a precipitant such as an acidified alum solution, under specified temperature conditions.

It is claimed that 3 to 5% resin additions give good wet strength and improve the bond to synthetic rubbers. Higher proportions of resin are said to give products suitable as filters, core stock, laminating paper, and molding stock.

The Snyder process has also been used to incorporate fairly high proportions of synthetic rubber latex in paper. According to one description (*25*), the latex is first added to the beater stock, followed by addition of the special phenolic resin and acidified alum solution by the same general procedure described above.

***Bardac Process (Cyanamid)***

This new process is being considered for the incorporation of various emulsion-polymerized resins as well as other resinous emulsions and dispersions (*26*, *27*). The method involves pretreatment of pulp with the proper amount of melamine-resin acid colloid usually 1 to 5% based on the weight of pulp and allowing the treated pulp stock to age a short time under slightly acidic conditions. Emulsions or dispersions of resins made with certain anionic dispersing agents can then be added to the stock and will be flocculated or precipitated on the fibers within a few minutes, after which the sheet can be formed in the normal manner. The exact mechanism is not known, but it might be termed a controlled flocculation process, as the resin is deposited slowly as fine flocs on positively charged fibers.

Several emulsion-polymerized materials such as polystyrene, polyethyl acrylate, and various vinyl resins and copolymers have been added successfully to pulp and made into sheets containing 10 to 50% resin on the total sheet weight during semicommercial paper-machine trials. Potential applications include the production of cellulose-base plastics, resin-treated pulp preforms, artificial leather-type sheets, and numerous specialties.

***Copolymers of Butadiene and Styrene (Latex Fiber Industries)***

This process, described in a recent patent to Owen (*28*), consists of adding specified copolymers (GR-S type) to stock after beating, together with the necessary compounding ingredients. The latex is precipitated with alum at any convenient point subsequent to mixing of the latex with the fibers. The finished sheets are claimed to be suitable for coated and embossed artificial leather, shoe counters, and other products. It is believed that this process is more satisfactory for making heavy rather than lightweight sheets. Of course, there are many other processes based on the use of alum, but usually they are more complicated than the one just cited.

***Problems in Beater Addition***

In addition to the methods described briefly above, it is known that many other procedures are being tried by paper and board mills around the world but it is too early to know how much progress has been made. It would appear that of all the methods available or under development some of them undoubtedly will prove successful for specific applications. It is also apparent that there are many difficulties in the way of finding a foolproof method of adding any desired resin to paper with no more difficulty than normally experienced with a material such as rosin size.

Some of the trends that are becoming evident from all of this work are as follows:

1. The resin or latex must be precipitated or deposited on the fibers as fine aggregates rather than as coarse lumps or there will be many difficulties such as spots in the sheet, sticking on the papermaking equipment, and slow drainage on the wire or cylinder.
2. Resins or rubbers that are tacky at room temperature adhere to the pulp fibers fairly easily during the stock-handling and sheet-forming steps, but also have more tendency to clot the fibers with resultant loss of desirable properties in the finished sheet.
3. Nontacky resins have little clotting tendency but are more difficult to retain and hold on the fibers with good distribution in the finished sheet.
4. Many processes yield sheets of good properties on a small

scale but drainage of water from the stock is slowed up to the extent that the process is impractical on a full-scale basis.

5. The complex technical control often necessary to make a process work increases costs and a single slip-up may be much more serious in spoiling material and causing down time than is the case with normal paper-mill operations.

For further examination of the subject of resin bonding of paper fibers, two specific fields have been selected. The first is the treatment of paper by flexible, rubbery materials such as the natural and synthetic rubber latices and certain synthetic resins, by either beater addition or saturation procedures. The second is the use of thermosetting resins to impart wet strength to paper.

## TREATMENT OF PAPER WITH FLEXIBLE POLYMERS

A complex set of variables governs the effect of the presence of elastomers in a sheet of paper on the physical properties of the treated sheet. Much work has been of an empirical nature, consisting of preparing the sheet with available resins and seeing what happens, but the amount of fundamental data is increasing and should eventually be of assistance in achieving the desired results.

### *Strength Properties*

The tensile strength and flexibility of the resin play a large part in determining the properties of the final sheet. In general, the stiffer resins impart higher tensile strength but at the expense of flexibility. The adhesion of the rubber or resin to the fibers obviously is of importance and many of the fundamentals of adhesion have been developed in recent years (*22*, *29–33*). Some of the important factors include molecular attraction between the resin and fiber, tack temperature and cohesive strength of the resin, and distribution of the resin in the sheet. Application of some of the known principles to any specific system must be made with caution, however, as some unknown factor may interfere with the expected result.

A disturbing feature about the addition of rubbery materials to paper is that one can add a large amount of the rubber to a very free or "unhydrated" sheet and obtain a tremendous increase in practically all of the standard physical tests for paper. However, when a sheet of the same weight is made from well-beaten pulp without the resin or rubber, it often is found that physical properties will be in the same range as those of the resin-treated sheet, with the exception probably of elongation under tension and edge tear resistance. Likewise, when flexible resins are added to stocks of varying freeness, the increases in strength obtained from a given amount of resin generally decrease as amount of beating is increased. These phenomena have been discussed by Oliner and O'Neil (*3*). In some instances, beater addition of elastomers causes a decrease in many of the commonly tested strength properties of paper (*25*).

In general, experiments with a wide variety of elastomers would indicate that impregnation of a formed sheet gives somewhat better over-all tensile, elongation, burst, and edge tear results than incorporation of the same amounts of elastomer by most beater addition processes. It is believed that this is because there is better "film" continuity and adhesion to the fibers in the case of the impregnation procedure. The above statement is based upon the use of pulps beaten to the same degree, and of course refers only to rather free stocks. On the other hand, there are indications that in heavyweight papers much better sheets can be prepared by beater addition.

It is not meant to imply, however, that there is little place for beater or slush-stock addition procedures. It is believed that there will be increasing usage of beater addition procedures as better methods are found for taking full advantage of the combined effects of both the natural cellulose-to-cellulose bonds developed by beating and the fiber-resin-fiber bonds theoretically obtainable by the use of resins.

Another serious problem in the manufacture and use of elastomer-treated papers has been the lack of precise test procedures that will really show whether or not the sheet is suitable for the intended use. Many of the flexible, leatherlike sheets containing elastomers are intended for use where properties such as toughness, flexibility, softness, edge or initial tear, cuttability, sewability, strength at a sewn seam, etc., are highly important. The difficulty in testing for such qualities on a scientific basis has been evident for some time.

For example, it has been found generally that hand-edge tear evaluations often do not correlate with results obtained by any of the existing tear or initial tear-testing instruments. Elongation plays an important part in hand tearing and several laboratories have suggested that use of stress-strain relationships may provide a quantitative evaluation of initial tearing resistance. It would appear that some of the newer techniques now available for stress-strain studies would be applicable (*34–36*).

Probably the most important factor in determining the future of resin-treated paper, especially by the beater addition method, is that of costs. Most elastomers sell for about 25 cents per pound or more (dry basis), and obviously more uses will be found if prices can be reduced. At the same time, selection of a process in which white water and broke losses are at a minimum, and machine speeds are maintained, is of prime importance regardless of resin-selling prices. The use of low-cost diluents for the higher cost resin is another approach.

Just as important, and sometimes neglected, is the necessity for adequate market research and close contact with prospective users of resin-treated papers so as to determine where the paper can be sold and whether the prospective user can pay for the costs plus a reasonable profit. It is quite possible for a mill to develop a very nice treated paper for which there is no market at the required price.

## WET-STRENGTH PAPER

Here is a field where very substantial progress has been made commercially by paper mills in the resin bonding of cellulose fibers, and where intensive research has assisted in making this progress possible, as well as indicating avenues for further improvements. Although other materials and procedures for imparting wet strength were and still are being used, the principal factor which made possible the widespread production of wet-strength paper was the discovery of the melamine resin acid colloid process for beater or slush-stock addition by Wohnsiedler, Thomas, Maxwell, and

Landes (*37–40*). This development occurred about 1942 and was followed shortly by the development in several countries and by various resin-producing companies of urea resins also suitable for beater addition.

Usage of these melamine and urea resins has expanded rapidly, and it has been estimated that over seven million pounds of these resins were used in the

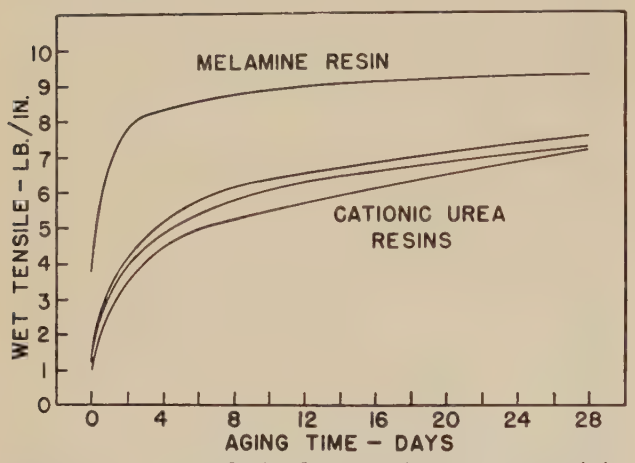


***Fig. 1. Wet strength development in papers containing melamine and cationic urea resins, dried and cured at 70°F.***

United States in 1948 (*41*). Undoubtedly the present rate of consumption is considerably higher and is still increasing. The diversified uses of the resins for improving both wet and dry strength and other properties have been well covered in the literature, as evidenced by the excellent review prepared by Collins and Adrian (*42*). Of special interest is recent work on the use of thermosetting resins to improve the dry-strength properties of paper (*43, 44*).

### *Melamine Resins*

More fundamental information is available on the melamine resin-acid colloid process because it has been available longer and the chemical make-up of the resin is known publicly and can be taken into account by investigators generally. In addition to patent information (*37*), the most comprehensive investigations reported to date have been those of Steenberg and Ivarsson (*45, 46*), Dixon, Christopher, and Salley (*47*), and several others (*40, 48, 49, 78, 79*).

The formation of the resin colloid in the presence of an acid (such as hydrochloric acid) may be visualized about as follows, based on information available to date:

(a) The methylol melamine monomer or polymer of low molecular weight reacts with aqueous acid to form a completely dissociated salt which has a strong positive charge but few bound anions.

(b) Polymerization takes place and at the same time some of the hydrogen ions are lost and more anions bound, giving a reduced but still positive electrostatic charge.

(c) At this stage the polymer particles are shaped somewhat like cylinders having a diameter of about 8 to 10 A. and a length of about 20 to 100 A. Some larger particles also are present, but all are in the lower portion of what is considered to be the colloidal size range—namely, 10 A. to 5000 A.

The situation becomes still more complicated when considering the reactions of the resin colloid with cellulose fibers and its retention through the papermaking process and subsequent effect in bonding together the fibers in the dry sheet. A simplified statement of the process is as follows (*43*): Upon contact of the resin polymer with cellulose fibers in water suspension, the bound anions are liberated and replaced by the cellulose. This process is largely irreversible under normal papermaking conditions. The reaction during drying of the sheet is discussed later.

A very important development from both the practical and fundamental viewpoint has been discovery of the importance of anions and especially the divalent sulphate anion in the melamine wet-strength process. The sensitizing effect of sulphates in promoting the flocculation of the resin colloid on cellulose has been well described by Steenberg (*46*). Other work has shown that the presence of a small amount of sulphates in the solution permits the binding of additional hydrogen ions as well as sulphate ions to the resin particles, with the net positive charge remaining at a minimum. Under these conditions the number of exchangeable anions is at a maximum (*47*).

It is obvious that the presence of divalent anions both in the pulp and process water, at the point of resin addition, is an important factor in determining retention and efficiency. The practical benefits to be obtained from control of sulphate ions have been shown by Maxwell and Reynolds (*48*), and numerous instances of improved commercial results are known. At least one of these has been published recently (*50*) wherein aluminum chloride was substituted for alum.

Although it has been found that the wet strength obtained with the melamine resin colloid is approximately proportional to the amount of resin retained in the paper, there are indications that this generalization is not strictly correct. For example, as the sulphate content of the water is varied the maximum retention and maximum wet strength are obtained at somewhat dif-

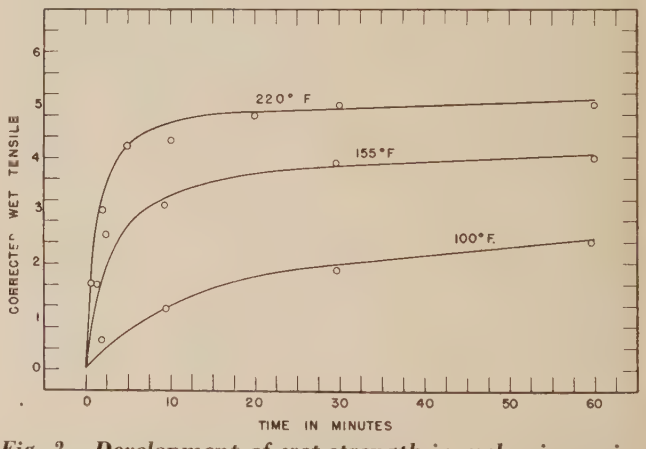


***Fig. 2. Development of wet strength in melamine resin-treated paper cured at various temperatures***

ferent sulphate values. Other factors also may be involved and this whole subject is receiving further study.

### *Anionic Urea Resins*

Following the introduction of the melamine resin colloid process for beater addition there was, of course, intensified interest in the development of special urea-

formaldehyde resins which could be added to the slush stock and which might be produced at a lower cost than the melamine resins. Whereas most of the previous work with urea resins had been based on obtaining water-dispersible products which could be precipitated out of solution or which would hydrophobe out upon dilution, etc., it was realized (based on the melamine resin colloid characteristics) that it might be desirable to obtain a resin polymer of fairly high molecular weight but which was still water dispersible. There also had to be some means of fixing the resin particles on the fibers without the formation of large resin agglomerates or spots in the sheet.

Unfortunately, very little detail of resin formulation is available publicly to date, but from what is known the developments have generally been along the following lines. Several companies are manufacturing anionic urea resins which would appear to be urea-formaldehyde-bisulphite reaction products or their equivalent. Limited information is available concerning some of these resins (*51–57*), and it has been indicated that sulphonate or methylene-sulphonate groups are present in the resin. There is also the possibility that formaldehyde-bisulphite complexes may be present, independent of the methylol-urea products.

Of course this type of resin is anionic, and cannot be deposited on the pulp fibers easily except by the use of cations such as that supplied by the aluminum ion of aluminum sulphate. The role of cations in the retention of the resin is quite mysterious, the amounts required depending upon such factors as contact time and stock consistency. Salts present in the pulp must be taken into account in drawing any conclusions from experimental work.

It has been reported several times that the anionic UF-bisulphite resins show much better efficiency with unbleached kraft pulps than bleached types of fiber, and this generally has been borne out by commercial ex-

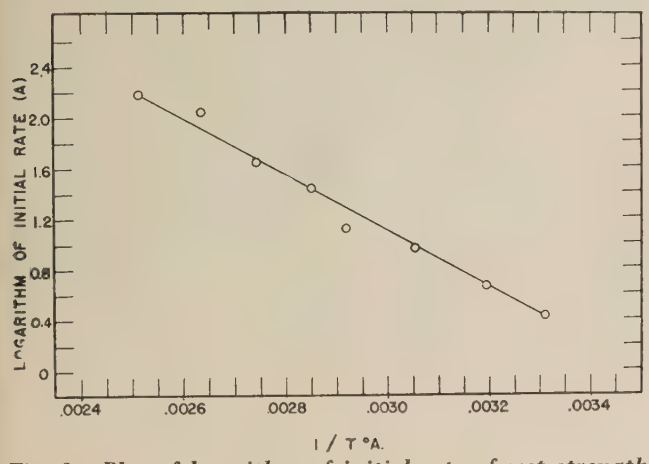


***Fig. 3. Plot of logarithm of initial rate of wet-strength development vs. reciprocal of absolute temperature***

perience (*58, 59, 73*). It is interesting to speculate whether it is the lignin in a certain pulp that directly affects resin retention and other efficiency factors. Another possibility to consider is that aluminum ions are bound to the pulp by lignin or lignin compounds and in turn are able to attract or flocculate the anionic resin particles. In this connection, reference is made to the statements by Brauns (*60*) concerning the sorption and charge properties of lignin and lignin sols.

***Cationic Urea Resins***

The most recent major development in urea resins for beater addition has been the introduction of modified urea-formaldehyde resins that will be retained by fibers without the use of an auxiliary fixing agent such as alum (*52, 56, 57, 61, 62*). Quite a few companies in the United States are producing such resins commercially

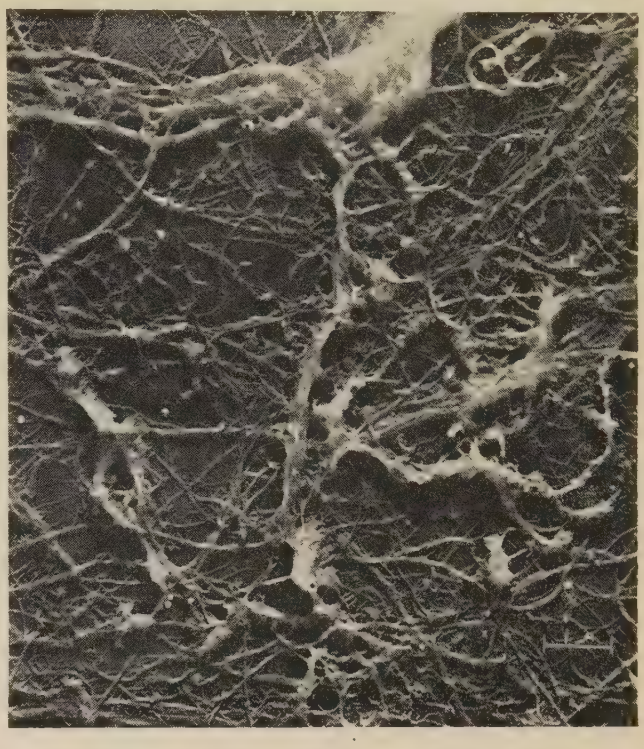

***Fig. 4. Electron micrograph of beaten pulp without resin (specimen uranium shadowed—negative print)***

and satisfactory results are being obtained. These resins can be used with all types of pulp and in some cases are employed without alum (e.g., for toweling), where the presence of alum would reduce absorbency. They can also be employed in all types of furnishes containing alum, as the alum serves as a catalyst for curing the resin.

Very little has been published about the nature of these cationic urea resins, and undoubtedly the composition of products on the market varies so widely that correlation of chemical nature with wet-strength efficiency is impossible at this time. In several instances, it is believed that the desired objective is obtained by incorporation of additional polar basic groups, such as amino or imino groups, into the urea-formaldehyde condensation product, by means of polyfunctional additives. Two such modifiers (guanidine, polyarylbiguanide) have been disclosed in connection with the manufacture of wet strength paper (*63, 64*). It should be noted that the two-$NH_2$ groups present in urea do not confer much basicity to urea because of the presence of the acidic C=O group.

In any event, it is evident that the introduction of additional polar basic groups permits condensation of the resin to a sufficient particle size to give good wet strength without, at the same time, causing undue viscosity increases or interfering with complete water dispersibility. Such resins appear to work with all types of

pulp and are not affected by the presence of anions to the extent that the melamine resin colloid is affected. However, retention of the cationic ureas is not usually as good as for the cationic melamine resin, and there is some evidence that the melamine resin is bonded more strongly to the pulp fibers.

***Mechanism of Bonding***

There are more theories on the bonding together of cellulose fibers in paper than there are for the bonding

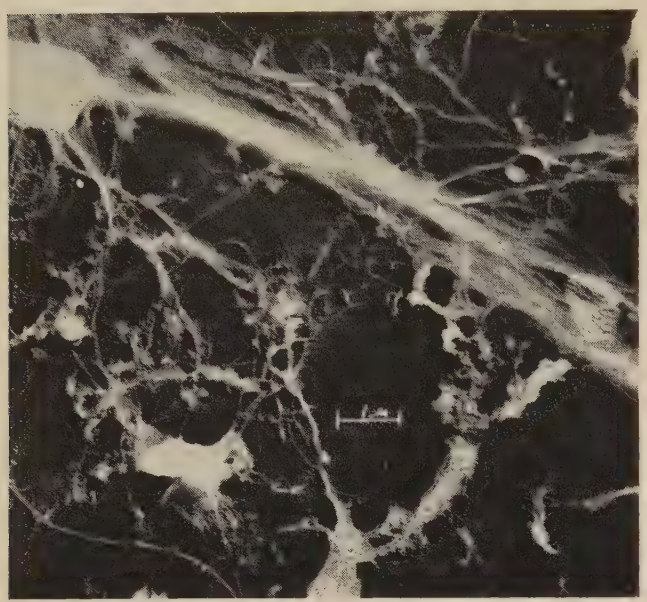

***Fig. 5. Electron micrograph of beaten pulp with melamine resin added (specimen uranium shadowed—negative print)***

of thermosetting resins to paper fibers, probably only because paper is older than synthetic resins, and scientists have had more time to theorize on cellulose. Since the nature of cellulose fiber-to-fiber bonds is still a subject of debate it is not surprising that many mechanisms for the fiber-resin-fiber bond have also been suggested (*42*, *46*, *47*, *51*, *56*, *57–59*, *65–70*, *78*, *79*).

Although many have postulated a chemical or covalent bond as being formed between the resin and cellulose very little evidence has been produced, at least in the case of wet-strength paper. It is interesting to note that at a recent symposium (*71*) on the adhesion of resins to cellulose fibers various types of polar bonds, hydrogen bonds, and covalent (or chemical) bonds were cited as possibilities for contributing to the bonding of thermosetting resins in general to cellulose, with hydrogen and covalent bonds being considered as the most probable with reference to wet-strength effects.

Unfortunately, the existing evidence for chemical reaction between cellulose and thermosetting resins is restricted generally to the high temperature and pressure conditions commonly associated with compression molding. Production of paper proceeds under much milder conditions and in this connection it is not usually realized that fairly good wet strength can be obtained in the laboratory by air drying resin-treated paper provided that sufficient time is allowed. In Fig. 1 are shown curves of the wet tensile strength of handsheets made from moderately refined unbleached Canadian kraft to which had been added 3% of various resins (solids basis) and 3% alum. The pressed wet sheets were air-dried on blotters by a fan at room temperature for 2 hours, and then placed in a conditioned room at 73°F. and 50% relative humidity. At intervals portions were soaked in water about 16 hours and tested for wet-tensile strength.

It should be noted that these handsheets received absolutely no "curing" other than at a temperature of 70°F. Attention is also called to the experiments reported by Maxwell and Reynolds (*72*) in which mention is made of the general curve of increased wet strength on aging of treated paper, followed by gradual loss of wet strength if temperature and relative humidity are raised moderately. From these results it might be postulated that either a good portion of the wet-strength effect obtained with melamine and urea resins is caused by bonds of only a moderate strength, such as hydrogen bonds, or that strong covalent bonds are formed but in a small number. A kinetic study of curing and hydrolysis rates should yield information of interest in this connection.

Some preliminary results based on curing rates of melamine resin-treated wet-strength paper are presented herewith. Moderately refined bleached kraft pulp was treated in slush stock form with 3% melamine-formaldehyde resin colloid in the usual manner. Sheets were formed, wet-pressed between blotters, and cut

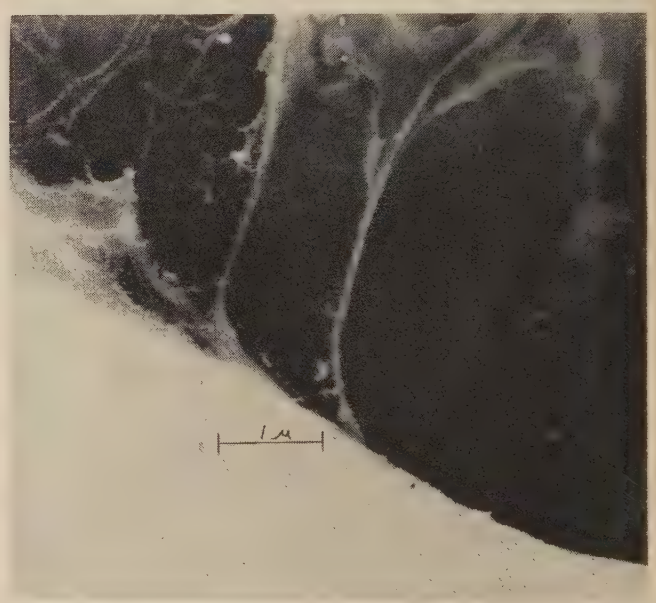


***Fig. 6. Electron micrograph of beaten pulp with melamine resin added (specimen uranium shadowed—negative print)***

into strips suitable for testing. Immediately after cutting, sets of wet strips were placed in a circulating air oven for varying periods of time at varying temperatures. As soon as each set was treated the strips were immersed in water at room temperature and allowed to soak 16 to 24 hours. After soaking, wet-tensile tests were made in the usual way.

Typical curves showing the development of wet-tensile strength during the first hour of cure are shown in Fig. 2. From the complete set of curves (curing tem-

peratures from 78 to 250°F.), it is possible by empirical methods to estimate the initial rate of wet-strength development at each temperature. As is well known, a plot of the logarithm of the velocity of a reaction vs. the reciprocal of the absolute temperature should give a straight line. That this holds for the present case is shown by Fig. 3, where the logarithm of the initial rate of wet-strength development is plotted against the reciprocal of the absolute temperature of curing. From the slope of the line, the apparent activation energy can be calculated; this is about 11,000 calories per mole.

This preliminary value of the apparent activation energy is somewhat lower than usually estimated for covalent bond formation, but higher than for hydrogen bonding, and its significance is not clear at the present time. It is quite possible that two or more processes are going on at once, so that the observed temperature coefficient is a composite of those for the several individual processes. It is evident that variations in technique should be employed in order to obtain more comprehensive and conclusive evidence. For example, an attempt should be made to separate the drying process from the curing process. In any event, it is believed that light can be shed on the nature of the development of wet strength by this general kinetic approach, and further work is in progress.

On the other hand, it is quite possible to formulate theories of bonding by wet-strength resins based entirely on mechanical effects, assuming that fibrils from more than one fiber are held together by cured aggregates. Still another theory has been advanced by Steenberg (*36*, *46*), who suggests that the resin treatment causes a decrease in hygroscopicity of the amorphous part of the fibers near their surfaces.

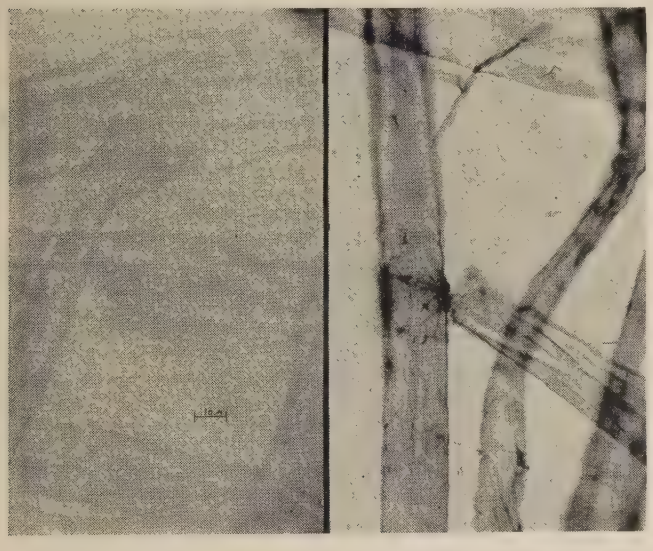

***Fig. 7. Photomicrographs of thin handsheets by transmitted ultraviolet light. Left: untreated; right: melamine resin treated***

### *Distribution of Resin*

Although it is tempting to formulate theories of bonding at the present stage, as was just done above, it is doubtful that anywhere near the right answer will be obtained without having a more complete picture of mechanical factors of sheet construction, such as the size and structural relationship of the fibers, fibrils, fiber debris, and other components both before and after sheet formation and drying. Progress is being made with the microscope, the electron microscope, and various less direct means but most of the work lies ahead.

Obviously, electron microscope studies offer a fertile field for adding to our knowledge, although there are some handicaps, such as the small field of observation, limits of resolution, and the hazard of changes that may occur in sample preparation. From studies to date it has been observed that small particles of melamine resin of about 100 to 200 A. in diameter collect in both irregular and regular distribution around small fibrils of about the same order of diameter and around bundles of unseparated fibrils ranging in diameter up to several thousand A. in diameter. Sometimes, it appears that the fibril is nearly completely covered with resin particles, but these cases are the exception and in no instances are there indications of continuous film formation. These observations apply both to slush pulp that has been dried and to disintegrated finished paper.

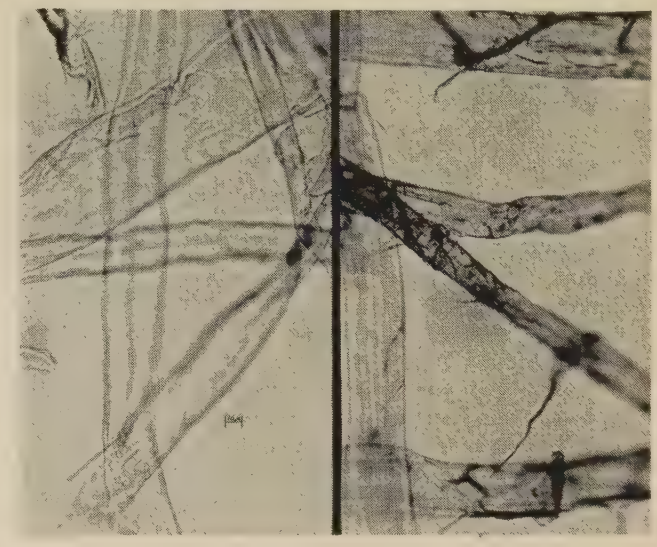

***Fig. 8. Photomicrographs of thin handsheets by transmitted ultraviolet light. Left: untreated; right: melamine resin treated***

A typical electron micrograph of moderately beaten bleached kraft pulp (uranium shadowed) is shown in Fig. 4. The same pulp treated with 3% melamine-resin colloid is shown in Figs. 5 and 6. Figure 6 in particular shows the resin particles very clearly attached to very small fibrils loosened from a larger fibril.

The electron microscope evidence cannot be considered without taking into account other evidence indicating that most of the resin particles in the colloidal form as added to the stock have an average length (assuming they are cylindrical in shape) between about 20 and 100 A.—in other words at or below the limit of resolution. Of course, it is possible that the resin particles aggregate at some stage in the process, but this has not been shown as yet. Therefore, it is quite possible that the portion of the resin contributing most to fiber bonding has not yet been shown and its distribution is not known. However, from the work of Salley and Blockman (*68*) and others it is believed that the wet-strength properties result largely from resin con-

centrated near the surface of the fibers and probably associated with the fine fibrils which must exist in tremendous numbers.

When one observes photomicrographs and especially electron micrographs of paper fibers, the complexities of the fiber and paper structures seem at times insurmountable. Each view is different and sometimes the indications may even be contradictory. These differences emphasize that long and painstaking work is required to draw valid conclusions and that no one method of attack can be relied upon alone. It is necessary to examine the fibers at all processing stages and at various magnifications, using as many sample preparation techniques as are available.

Although a few microscopical studies of resin distribution have been made (*73*), another line of approach recently undertaken may be of interest to other investigators (*74*). In this work, the ultraviolet microscope is employed using light of wavelength 2537 A. and taking advantage of the fact that melamine resin absorbs strongly in this range. In addition to studying dried pulp suspensions, thin tissuelike handsheets have been made and examined. Some photomicrographs of untreated and melamine resin-treated paper are shown in Figs. 7 and 8. It will be noted that the untreated fibers are nearly transparent, whereas the resin-treated fibers show up much darker because of the resin present. The two treated samples show a difference in apparent resin distribution, probably because of differences in the method of resin treatment. Interpretations of these results are incomplete at the present time.

There are several potentialities in the method outlined above. In the first place, there is no extra component added to the system as with dye-staining techniques. By the use of an actual sheet of paper, gross structure around the fiber-to-fiber bonds can be observed without disturbing the sheet in any way. Furthermore, correlations with actual sheet strength (both wet and dry) can be made if testing instruments of sufficient sensitivity are available. Obviously, there are some limitations to this method of study but it is hoped that valuable information will be obtained.

## FUTURE OBJECTIVES

At first glance it may seem that the only reason for studying the mechanism of bonding in wet-strength paper is to improve the efficiency of the resin treatment so that papermakers can apply resins to more grades of paper with the result that resin manufacturers can sell large tonnages of the resins. Without apologizing for such an objective, it is believed that research in this field may be of assistance in unlocking the mysteries of cellulose bonding generally, regardless of whether or not resins are present. After all, paper could not be made if the fibers did not bond together, and the nature of the bond and the cost of obtaining it play important parts in the future progress of papermaking.

The normal bonds between cellulose fibers cannot be seen; they can be studied only by indirect means. Furthermore, the surfaces of fibers are far from uniform, with differences in physical structure, charge properties, chemical composition, and other characteristics undoubtedly present with innumerable permutations (*75–77*). It is suggested that, in studying the relationships of very small resin particles with pulp fibers, we actually may have available a means of partially tracing or "staining" the areas at or near where normal bonding takes place. In other words, more knowledge of the distribution of resin particles and the forces holding them in place should contribute to a better understanding of the cellulosic part of the fiber-resin team.

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# The Influence of Hemicelluloses in Wood Pulp Fibers on Their Papermaking Properties

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It had been realized by practical papermakers, almost from the first introduction of sulphite wood pulp, that the method of cooking the raw material greatly influences the properties of the pulp. It has been known for many years, for example, that if a pulp was wanted which could be wetted in the beater very quickly and which, when suitably beaten, would produce a satisfactory greaseproof or tracing paper, it would be necessary to select for this purpose a sulphite pulp which had been produced by slow cooking and at low temperature, one preferably cooked by the indirect method such as a Mitscherlich cook. It has also been common knowledge for many years that such pulps, when beaten to less than greaseproof stage, produce very firm and strong papers as far as tensile and bursting strength are concerned. Similarly, sulphite pulpmakers very early found that if, in order to remove the lignin from the wood quickly, they drastically cooked it, using a short cooking period and high temperature, such pulp gave rise to lower strength paper. At first it was thought that it was the removal of the last remnants of lignin which caused strength reduction and, for a time, a theory was current that a small residuum of lignin in the pulp was necessary for high strength. This theory was subsequently abandoned and in fact we know now that not only does lignin not promote strength in pulp, but actually detracts from it. The lack of strength was then thought to be due to the degradation

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of the cellulose brought about when the last few per cent of lignin was being removed, when the cellulose was left unprotected against the action of the pulping chemicals, and this concept was used to explain the relatively low yields which always resulted from cooking conditions which led to a well-delignified but relatively weak pulp.

Although these effects were common knowledge to pulp and papermakers, the reason for them still continued to remain uncertain, although it began to be appreciated that pulps contained other bodies besides the cellulose and residue of lignin which they had hitherto been assumed solely to contain. Analyses of these pulps showed that they contained carbohydrate substances which, unlike cellulose, were readily hydrolyzed to sugars by dilute acids and which dissolved in relatively dilute caustic soda solution and, therefore, could not be cellulose; the investigators at this period were content to lump these constituents of pulp together under the term "other carbohydrates." It was then noted that the mildly cooked pulps, such as Mitscherlich cooked pulps, which were easily wetted and which gave rise to strong papers and were ideal for making greaseproof papers, contained a larger porportion of these "other carbohydrates" than the more drastically cooked pulps, which also to a great extent accounted for the higher yields obtained from the wood when these pulps were made.

Well before this time, however, our plant biologist friends had been busy in examining these very same "other carbohydrates," not so much those obtained from wood, although they did pay some attention in that direction, but mainly those derived from seed husks and the like, and one investigator—namely, Schultze—(about 1890) had given them a name—hemicelluloses. Various other names have been given to these "carbohydrates other than cellulose" by different investigators since then, but it is not within the scope of this paper to amplify this subject further, and in any case this nomenclature was admirably discussed in 1949 by L. E. Wise (*1*). I shall, therefore, adhere to the original term hemicelluloses in this paper. As a result of the work of these plant biologists and chemists, a great deal of the chemical and physical properties of these hemicelluloses became known, and several, such as mannan, glucan, xylan, galactan, araban, and some polyuronides, were isolated, and their properties determined.

Nevertheless, right up to the early nineteen thirties the influence of these constituents of wood pulp on the papermaking properties of the pulp were more or less completely ignored by chemists and physicists of the paper industry—for example, there is no mention of the term hemicellulose in C. J. West's Bibliography of Papermaking before 1936—and the theories developed up to that time regarding beating, paper strength, etc., were based solely on the chemical or the physical properties of normal cellulose. No doubt it was a hangover from the rag papermaking days, which caused cellulose alone to be envisaged as the sole participating agent in the various effects of beating which were known and in imparting strength to paper.

In 1933 a paper was published by Jonas and Rieth (*2*) which seemed to advance a *prima facie* case that hemicelluloses played a predominant part in beating effects and in influencing the strength of paper. These two investigators critically examined two sulphite pulps which beat at appreciably different rates and yielded papers of distinctly different strengths; they found that the only apparent difference between the two pulps was in the content of the hemicellulose mannan, which was 3% greater in the pulp which beat faster and possessed a higher strength.

The concept that the hemicellulosic portion of pulp played a predominant part in its papermaking properties received, however, its great stimulus from the historic work of Van Beckum and Ritter (*3*), who discovered a means of removing practically the whole of the lignin of woody material, leaving not only the cellulose but the hemicelluloses intact, and avoiding the partial hydrolysis and loss of the latter which occurs when the lignin is removed by the Cross and Bevan chlorination method. This total woody material minus only the lignin was termed holocellulose, and since Van Beckum and Ritter's first publication of their work, holocelluloses from different woods have been isolated and extensively examined, both from the point of view of their chemical composition and also their papermaking properties. It was soon found that holocellulose pulps tended to beat much more rapidly than the corresponding pulps containing the normal amount of hemicelluloses, that the stuffs produced were characterized by high bursting and tensile strengths, a tendency to beat easily to greaseproof paper, possessed rather unstable whiteness and, in fact, behaved like gently cooked, high-yield pulps of the Mitscherlich variety, only more so.

It was somewhere about this period that I myself carried out some beating tests on a number of commercial bleached wood pulps of different hemicellulose contents to see whether any of the common chemical constants for determining the chemical nature of cellulosic materials, such as alpha-, beta-, and gamma-cellulose values, copper number, cuprammonium viscosity, would be of any value in indicating the papermaking properties of commercial pulps (*4*). The results obtained showed that there was no obvious relationship between bursting strength and alpha- or beta-cellulose content of the pulp or with copper number or with cuprammonium viscosity. On the other hand, there did seem in general some relationship between bursting strength and gamma-cellulose content, although a complete relationship could not be expected since the gamma-cellulose fraction is very indefinite in composition, and may contain, besides the original natural hemicelluloses of the pulp, the products of deterioration of the cellulose in the fiber originating during the processes of manufacture of the pulp. Also, as the pulps were derived from pulp mills situated in different countries and in different regions of the same country, morphological differences would exist between the fibers of the different samples, which would have a major effect in determining bursting, tensile, and folding strength (*5*).

Nevertheless, the results of this investigation showed quite markedly that, when the pulp had a low gamma-cellulose content and at the same time a high alpha-cellulose content, showing that the natural hemicelluloses had been removed with minimum deterioration of the cellulose, such pulps had a low bursting strength.

This is very strikingly demonstrated if a strong bleached sulphite with a low beta-cellulose content and a

**Table I**

*Scandinavian strong bleached sulphite:*
*Alpha-cellulose* ..... 88.6%
*Beta-cellulose* ..... 0.8%
*Gamma-cellulose* ..... 10.6%

| *Beating time, min.* | *Burst ratio* | *Tear ratio* | *Standard bulk* | *Canadian freeness* | *Opacity: contrast ratio, (cor. to 85 g./sq. m.* |
|---|---|---|---|---|---|
| 0 | 0.43 | 0.64 | 1.71 | 702 | 85.6 |
| 8 | 0.86 | 0.86 | 1.51 | 586 | 82.6 |
| 16 | 1.16 | 0.81 | 1.37 | 455 | 80.6 |
| 24 | 1.37 | 0.77 | 1.36 | 317 | 76.2 |
| 32 | 1.48 | 0.69 | 1.28 | 219 | 70.1 |
| 40 | 1.53 | 0.70 | 1.19 | 138 | 60.1 |
| 48 | 1.63 | 0.62 | 1.15 | 81[a] | 53.0 |
| 56 | 1.69 | 0.68 | 1.12 | 47 | 45.5 |
| 64 | 1.60 | 0.56 | 1.10 | 25 | 43.7 |
| 72 | 1.63 | 0.57 | 1.05 | 14 | 43.7 |
| 80 | 1.64 | 0.50 | 1.10 | 11 | 39.4 |
| 88 | 1.66 | 0.46 | 1.02 | 26 | 35.4 |
| 96 | 1.65 | 0.38 | 1.04 | 38 | 36.7 |
| 25 | 1.40 | 0.77 | 1.30 | 300 | |

*Same pulp extracted with 7% caustic soda solution:*
*Alpha-cellulose* ..... 94.3%
*Beta-cellulose* ..... 1.8%
*Gamma-cellulose* ..... 3.9%

| *Beating time, min.* | *Burst ratio* | *Tear ratio* | *Standard bulk* | *Canadian freeness* | *Opacity: contrast ratio, (cor. to 85 g./sq. m.* |
|---|---|---|---|---|---|
| 0 | 0.22 | 0.33 | 2.22 | 702 | 83.7 |
| 16 | 0.50 | 0.64 | 1.78 | 601 | 87.6 |
| 32 | 0.66 | 0.63 | 1.58 | 442 | 86.7 |
| 48 | 0.73 | 0.56 | 1.50 | 289 | 86.6 |
| 64 | 0.81 | 0.55 | 1.38 | 180 | 85.6 |
| 80 | 0.88 | 0.52 | 1.39 | 109 | 84.1 |
| 96 | 0.91 | 0.46 | 1.27 | 81 | 81.2 |
| 104 | 0.84 | 0.44 | 1.24 | 81 | 80.9 |
| 112 | 0.88 | 0.44 | 1.24 | 98 | 80.3 |
| 120 | 0.88 | 0.36 | 1.20 | 122 | 79.5 |
| 47 | 0.72 | 0.57 | 1.50 | 300 | |

[a] Greaseproof.

high gamma-cellulose content, which therefore is presumably rich in natural hemicelluloses, is extracted with caustic soda solution. Table I shows the change in beating characteristics which occurred when a strong Scandinavian bleached sulphite pulp had its hemicellulose content reduced by digesting twice with 7% (weight per weight) caustic soda solution at room temperature. It will be noted that the pulp is not only considerably weakened in bursting strength but also, when the comparison is made on an equal freeness basis, in tear as well, showing that the fibers of the extracted pulp have been more shortened than the unextracted pulp. This shortening of the fibers will be referred to again later, as it has a very important effect on the beating of pulp with a low hemicellulose content. Further than this, beating time—i.e., time to a specific freeness—is much greater for the extracted pulp than for the original pulp, as is also the bulk. Referring to the opacity figures for the two pulps, it will be seen that, whereas the opacity of the unextracted pulp falls steadily from the commencement of the beating, the opacity of the extracted pulp tends to remain constant, and only falls off, and then only a little, when extreme degrees of beating have been reached. (Opacity was assessed by measurement of the contrast ratio with the Bausch and Lomb opacimeter, the figures obtained being then calculated to a sheet of basis weight 85 grams per square meter in order that the figures should be comparative.)

The conservation of opacity of the extracted pulp during beating suggests that, in contrast to the unextracted pulp, very little fiber-to-fiber bonding occurs as a result of beating, for, other things being equal, decrease in opacity must be a measure of the increase in bonding between fibers and this explains the low bursting strength and high bulk of the paper from the extracted pulp as compared with the unextracted pulp.

An effect as equally important as the reduction in strength of pulps when their gamma-cellulose contents are reduced, however, was noted in the investigation on the beating of commercial pulps—namely, the fibers of these pulps tended on beating to break up short and fragmentize and show considerably less fibrillation than normal papermaking pulps exhibited under similar beating treatment. The beating of the extracted strong bleached sulphite pulp referred to above, and for which figures are given in Table I, illustrates this difference. In Figs. 1A, 1B, and 1C are shown photomicrographs of the fibers of the original pulp and the extracted pulp when beaten for the same time (namely, 32 minutes) under the same beating conditions, when the freeness of the original pulp was 220 and that of the extracted pulp was 440, and also when beaten to almost the same freeness—namely, 180, the beating time then being 64 minutes. It will be seen that, although the fibers of the original pulp are well fibrillated and somewhat shortened, this shortening is due to the fibrillation of the pulp. On the other hand, the fibers of the extracted pulp show considerably less fibrillation, but a considerable proportion of the fibers appear to have broken up transversely and fragmentized without the splitting and shredding longitudinally which is characteristic of fibrillation. This in itself would account for the reduction in bonding and, consequently, reduction in strength and increase in bulk and lack of reduction of opacity, and also for the slow rate of freeness reduction.

This behavior under the beater roll of fibers practically devoid of hemicellulose must be due to their lack of plasticity. Now the plasticity of a fiber may be assumed to be related to its swelling capacity in water. Jayme and Lochmüller-Kerler (*6*) determined the swelling capacity in water of sulphite pulp fibers made from the same wood (beech) and containing varying proportions of hemicellulose (pentosan, etc.) by indirect

**Table II. Beech Sulphite Pulp**

| *Yield on wood (moisture-free), %* | *Alpha-cellulose, %* | *Pentosan, %* | *Over-all strength index* | *Water retention (swelling capacity)* |
|---|---|---|---|---|
| 62.64 | 64.78 | 19.61 | 27.85 | 148 |
| 50.62 | 79.81 | 14.95 | 44.42 | 129 |
| 49.95 | 80.62 | 13.23 | 42.96 | 114 |
| 48.20 | 83.20 | 11.57 | 43.46 | 118 |
| 44.37 | 86.22 | 9.54 | 36.00 | 111 |

means, by measuring the water retention after centrifuging under standard conditions (*7*); their results showed that, the greater the hemicellulose content, as shown by the yield or the pentosan content, the greater was the swelling capacity as shown by the water retention. Some of their results are shown in Table II.

***Fig. 1A. Original bleached sulphite pulp beaten to 220 C.F.***

Young and Rowland (*8*) had previously determined swelling directly by means of a special dilatometer, and their results on several softwood pulps obtained in this way and related to pentosan contents of the pulps are given in Table III.

**Table III. Comparison between Pentosan Content and Swelling Capacity of Softwood Pulps**

| *Pulp* | *Pentosan content, %* | *Swelling capacity* |
|---|---|---|
| No. 1 Alpha | 2.4 | 42.0 |
| Bleached sulphite | 4.5 | 54.0 |
| Bleached sulphite | 4.7 | 57.0 |
| Bleached sulphite | 6.7 | 57.5 |
| Unbleached sulphite | 6.9 | 58.0 |
| Unbleached Mitscherlich | 6.9 | 60.5 |
| Unbleached sulphite | 7.4 | 57.5 |
| Bleached Swedish kraft | 10.8 | 63.5 |
| Unbleached kraft | 10.9 | 79.0 |
| Groundwood (spruce) | 11.6 | 87.5 |
| Bleached sulphite | 11.7 | 93.0 |
| Southern kraft | 12.6 | 96.0 |

[Incidentally, from this work of Young and Rowland there appeared to be, in the case of softwoods, a linear relationship between pentosan content and swelling capacity. The same authors, however, found that such a linear relationship between pentosan content and swelling capacity did not hold in the case of hardwoods, although it appears it did so in the case of Jayme and Lochmüller-Kerler's beechwood pulps shown in Table II.]

Since swellability in water can be assumed to be a measure of the degree of plasticity which a fiber attains on soaking in water, the greater the amount of hemicellulose a fiber contains, the more plastic it will be when soaked in water. Thus, a fiber containing a low proportion of hemicellulose, and thus possessing low swelling capacity, will be relatively nonplastic when soaked in water. The pressure of the beater bars will thus be restricted to a small area when the bars strike the fiber and will not be distributed by the plastic flow of the material and, consequently, the fiber will tend to break at the point where it is hit by the bar instead of being shredded or fibrillated. The effect may be likened to the result of striking a piece of baked dough as compared with the moist unbaked material. If the former is struck with a hammer, it breaks in two where the blow falls, or fragmentizes at that point. In the case of the unbaked moist dough, however, this is a plastic material so that, when it is struck, it simply flattens and squeezes out at the point where it receives the blow but does not splinter.

The role of hemicelluloses in acting as plasticizing agents for fibers appears to be, therefore, a most significant role of these substances in papermaking.

However, whereas the plasticity of a fiber increases continuously with its hemicellulose content right up to the maximum amount of hemicellulose contained in the original wood, Jayme and Lochmüller-Kerler have shown that the strength of paper made from the pulp does not do so, but reaches a maximum at a certain hemicellulose content and then begins to fall. These authors (*9*) prepared beechwood pulps of different yields

***Fig. 1B. Extracted bleached sulphite pulp beaten to 440 C.F.***

directly by mild sulphite cooks and bleaching with sodium chlorite in several steps; after beating these pulps to 50° S.-R. and determining the strength of the paper made therefrom, they found that the maximum over-all strength value, made up of breaking length, bursting strength, folding strength, and tear, occurred

at a yield figure of 50 to 52% (see Table II and also Fig. 2). The individual strength properties, on the other hand, developed their optimum values in different yield ranges. For instance, the maximum breaking length is obtained at a pulp yield of 53%; that of bursting strength at 54%; of elongation at 57.5%; of folding strength at 53.1%; and of tear at 47%; the optimum over-all strength value at 51% yield is a compromise of these individual values. As a matter of interest, this bleached sulphite of maximum over-all strength contained 80.9% alpha-cellulose (containing 2.8% pentosans insoluble in caustic soda), 1.1% lignin, 8.7% pentosans, and 9.3% of other hemicelluloses (probably chiefly glucan), both latter constituents being soluble in 17.5% NaOH. The copper number was 1.15 and the average polymerization degree was 1430 by cuprammonium viscosity and 1660 by the nitrate method.

The authors found that, when a bleached pulp was obtained in a higher yield than 51% and a small amount of hemicellulose was removed from the pulp by extraction with 0.2% caustic soda, the over-all strength of the pulp was increased (see point *A*, Fig. 2), verifying the dependency of maximum strength upon a definite hemicellulose content.

Jayme gives two explanations for the phenomenon of an optimum hemicellulose content at which maximum strength is attained. (1) The strength of paper depends not only on the extent of the fiber bonded area but also on the intrinsic strength of the bonding. The increased amount of hemicellulose remaining in the

*Fig. 1C. Extracted bleached sulphite pulp beaten to 180 C.F.*

pulp as the yield of pulp from the wood increases means that the pulp contains increasing amounts of shorter chain hemicelluloses which are the most easily hydrolyzable, and which are removed when the more drastic isolation treatment giving lower yields is applied. The increasing proportion of such short-chain hemicelluloses will progressively decrease the intrinsic strength of the bond. Therefore, the presence of increasing amounts of hemicelluloses in the pulp causes two opposing effects on strength: increasing bonded area due to increased plasticity of the fibers; and decreasing intrinsic strength of the bond due to the presence of low-chain-length

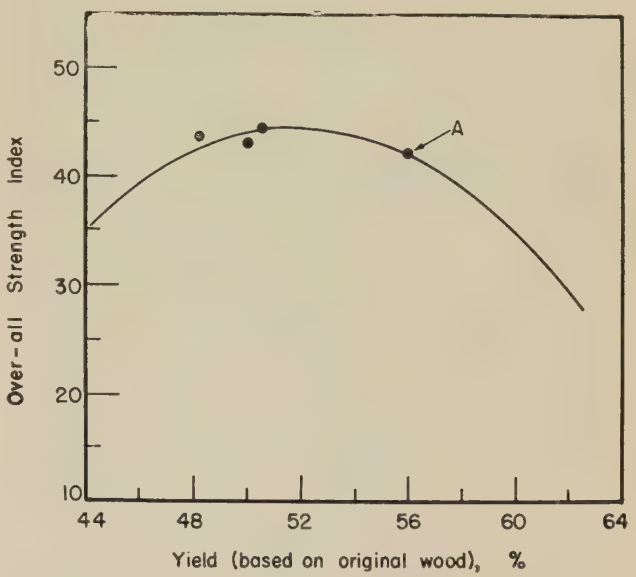


*Fig. 2. Relation of over-all strength to yield*

hemicelluloses. At low pulp yields, the intrinsic bonding strength is higher but the bonded area is lower, whereas the reverse is the condition at high pulp yields. Somewhere in between there is a compromise and this is the optimum position for maximum strength. (2) Another reason for the existence of an optimum hemicellulose content in relation to strength is that, as the amount of hemicellulose in the fiber increases, the proportion of cellulose, the long chain constituent which confers strength to the fiber itself, must decrease, so that increasing amounts of hemicelluloses in the fiber progressively reduce the intrinsic strength of the fiber, and thus weaken the structure as a whole, so here again at a certain pulp yield point, a maximum strength is attained, when the sum of bond strength and fiber strength is at a maximum. All the foregoing suggests that, in order to relate strength to hemicellulose content, it is not sufficient to determine the quantity of hemicellulose present in the pulp, but it is just as essential to determine its nature.

This work of Jayme and Lochmüller-Kerler, demonstrating that there is an optimum hemicellulose content at which maximum strength occurs, has received confirmation from some interesting work by R. E. March (*10*). March used a somewhat different method from that of Jayme and Lochmüller-Kerler. Whereas the latter investigators obtained pulps with different hemicellulose contents by treating the wood raw material to different severities of cooking and chlorite bleaching, thus varying the yields of pulp, March started with a somewhat over chlorited holocellulose—over chlorited to ensure that the lignin content was negligible; thus, March started with a pulp containing almost the whole of the hemicelluloses originally contained in the wood,

and then reduced these stepwise by partial extractions of the pulp with caustic potash solutions of different strengths. Instead of beech, which was the wood used by Jayme and Lochmüller-Kerler, March used aspen because of its low lignin and extractive content and its high hemicellulose content which mainly consists of

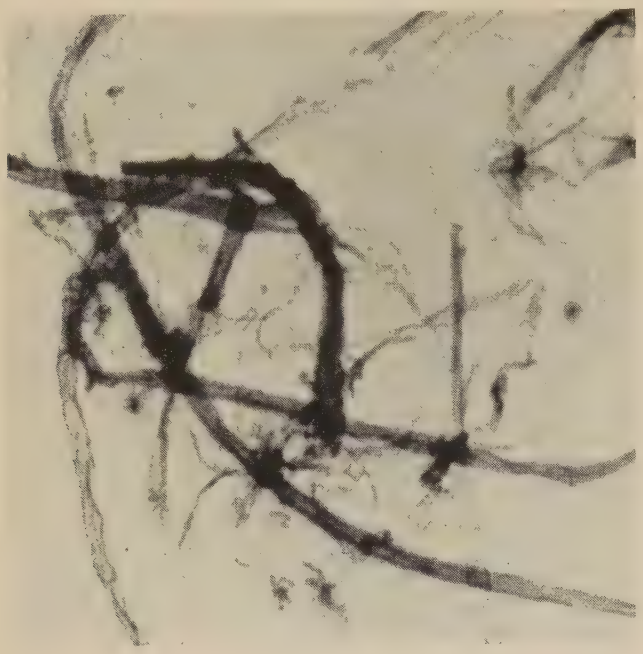

*Fig. 3A. Rag pulp beaten to 137 C.F.*

xylan and only a slight amount of mannan. On beating these partially extracted holocellulose pulps to 500 S.-R. freeness, March found that the bursting strength curve and the translucency curve passed through a maximum when the holocellulose had been extracted with 1% caustic potash solution and the pulp then contained about 13% xylan, whereas the tearing strength curve passed through a minimum at 11% xylan content.

This work of March also confirmed the other deductions of Jayme's to which we have drawn attention—namely, that the nature of the hemicellulose, as well as the quantity of it, is of considerable importance in influencing the strength of the paper made from the pulp. For example, a bleached sulphate pulp, made from the same aspen wood as the holocellulose, and which contained 18.1% xylan by analysis—i.e., almost the same xylan content as the 18.9% which the holocellulose contained—gave a much lower bursting strength and translucency and a much higher tear than the latter and, in fact, behaved as though it only contained 9% of xylan. On an alkali-extractable hemicellulose basis, the correlation of the papermaking qualities of the kraft pulp with those of the holocellulose and its products was better than when it was based on xylan content, but, even on this basis, the sulphate pulp with an alkali-extractable hemicellulose content of 12.6% had a bursting strength of only 117 as compared with 149 for the sample of alkali-extracted holocellulose possessing almost the same extractable hemicellulose content—namely, 12.5%. Actually, from the bursting strength point of view, the sulphate pulp behaved like an extracted holocellulose containing only some 9% of alkali-extractable hemicelluloses.

This lack of correlation in many instances between the hemicellulose content of a pulp and its papermaking properties brings us to a very important consideration, which should be fully appreciated. In determining the relationship between hemicellulose content and papermaking properties, nearly all the investigators whose works have been discussed up to now have based their conclusions on pulps or holocelluloses which have not only been obtained from the same wood, which is essential, of course, to avoid differences due to morphological variations in the raw material, but also each investigator adhered to one type of treatment for obtaining the pulps or holocelluloses whose papermaking properties he was comparing, and only varied the extent of the treatment given to the raw materials, so as to obtain the pulps or holocelluloses with the different hemicellulose contents required. Thus, Jayme and Lochmüller-Kerler varied the time of cooking to vary the yields (and, consequently, the hemicellulose contents) of the pulps with which they worked. With the exception of the bleached sulphate pulp, the properties of which, as we have seen, did not correlate with the properties of his other products, March produced one holocellulose directly from the wood by the chlorite process and then extracted this with different strengths of KOH solutions to obtain his pulps with different hemicellulose contents. F. T. Ratliff (*11*) kept temperature and liquor composition constant and varied the time factor in the case of four out of the five pulps he

*Fig. 3B. Wood pulp beaten to 215 C.F.*

obtained, although in the case of the fifth pulp he modified all three factors.

This procedure (when treating a single raw material) of only varying the treatment in degree or extent is perfectly logical and justified when we wish to determine the effect on the papermaking properties of the fiber of varying the amount of a particular combination

of hemicelluloses without varying the composition. There is no doubt that, when the nature and the composition of the hemicelluloses in a fiber is kept constant (which can be done more or less by adhering to the same treatment for isolating the pulps), and only the amount of these hemicelluloses is varied by varying the extent of the treatment, the relationship between hemicellulose content and papermaking properties of the fiber is adequately formulated by Jayme, Ratliff, March, and the other workers on the subject.

We have already noted, however, when discussing March's work on the effect of the stepwise removal of hemicelluloses, that a pulp obtained by sulphate cooking had, at the same hemicellulose content, or the same xylan content, very different papermaking properties from the pulp which was obtained from the wood solely by chlorite treatment and then extraction with 1% caustic potash. This variation in papermaking properties of the pulp with the treatment which the wood received to produce it is confirmed by Jayme, Wagenbach, and Deloff (*12*). These observers found in cooking beechwood by both the sulphate and soda processes, that varying the composition of the cooking liquors had a decided influence upon the properties of the pulps obtained.

This aspect—namely, the effect of different conditions of treatment in obtaining the pulp from the wood—has been specially studied by J. H. Ross (*13*). Ross analyzed the results of a whole series of cookings of spruce, balsam, and Douglas-fir carried out by J. S.

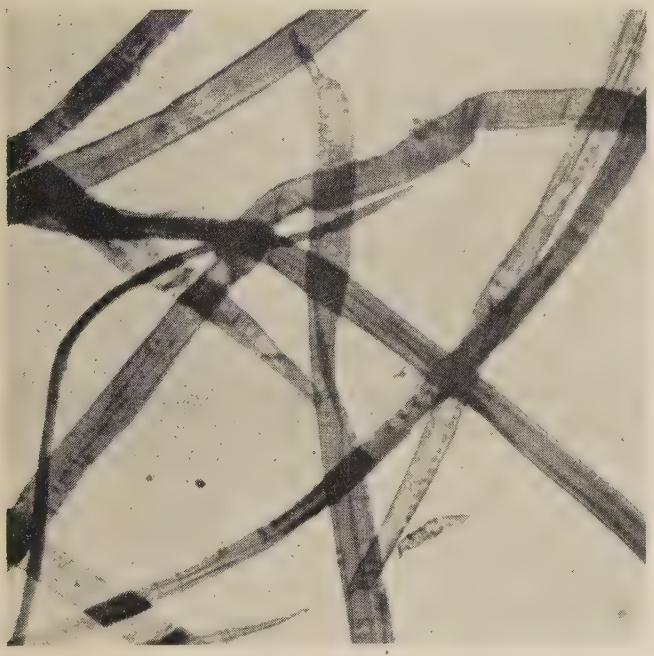

*Fig. 4A. Scandinavian strong kraft paper*

Hart and R. K. Strapp of the Pulp and Paper Research Institute of Canada. Ross concluded from his analysis that, when pulps are compared on the basis of equal lignin contents, differences in papermaking qualities appear to be affected more by cooking liquor composition than by the composition of the pulps.

Generally speaking, however, the greatest difference between pulps having the same composition, but obtained under different conditions of cooking liquor, appeared to be in beating time, but care should be taken in placing too much significance on this. Hart and Strapp measured beating time by the time taken for the pulp to drop to 300 freeness or to 100 freeness. This is,

*Fig. 4B. Scandinavian strong M.G. sulphite paper*

of course, the conventional method of assessing beating time, and is quite satisfactory for routine work in the mills where the main objective is to ensure that the stuff possesses regular drainage properties on the wire of the paper machine. But is it a sound method for determining the degree of processing a pulp requires? My own personal experience is that beating time based on freeness is the most variable of all the characteristics of a pulp, no matter whether laboratory or mill beating equipment is used. Small differences in the amount of fines in the pulp, either prior to the beating or produced during the beating, will vitally affect the freeness readings. For example, Hart and Strapp's pulps 171 and 172 have been cooked in exactly the same way, with cooking liquors of the same composition. The yields and compositions of these pulps are the same, so that the pulps may be regarded as identical. Nevertheless, there is 8% difference in the beating time at 300 freeness and 14% difference at 100 freeness!

James d'A. Clark (*14*) vividly emphasized the shortcomings of the freeness test as a scientific test. While, therefore, I would not dispute that the methods of isolating the pulp from the wood, as well as the composition of the pulp, have an influence on beating time, I think we must not allow Hart and Strapp's data to cause us to exaggerate this effect, and I think we should only draw definite conclusions when there is a decided difference between the figures for beating time determined in this way.

As regards strength (bursting strength), there is no doubt that the method of treatment for obtaining the

pulp from the wood has a decided influence in addition to the hemicellulose content. This is illustrated by the Hart and Strapp results. Thus, for example, their cook 164, a straight soda cook, gives a burst of 91 at 300 freeness; their cook 166, a cook with liquor of low sulphidity, gives a burst of 95, although the hemicellulose contents are substantially the same; whereas cook 171, made at a high sulphidity, gives the highest burst, although the hemicellulose content of the pulp obtained is definitely lower than those of cooks 164 and 166. The foregoing shows the effect of changing from a soda to a sulphate treatment. The change from a sulphate treatment to a chlorite treatment is still greater, as we have seen from the work of March, for, whereas the pulp obtained by the chlorite treatment with alkali-extractable hemicellulose content of 12.5% had a bursting strength of 149, the kraft pulp from the same wood with an alkali-extractable hemicellulose content of 12.6% had a bursting strength of only 117.

Now why, in addition to the amount of hemicellulose in a fiber, should the particular treatment for obtaining it from the wood affect its papermaking properties? Ross suggests the following possibilities to account for this result: (a) selecting different original materials in the wood for removal; (b) causing modification of the original material; and (c) causing modification of the physical structure of the fiber itself. Putting aside possibility (c) for the time being, the first two possibilities [(a) and (b)] seem to amount to the same thing in the end, that the treatment for obtaining the pulp from the wood determines the composition of the cellulose or the hemicellulose components of the pulp or both, and thus determines the characteristics of these components of the fiber.

In the main, this can only mean differences in the degree of polymerization of either the cellulose or the hemicellulose or both. Since, in most cases, the amount of hemicellulose in a fiber is only a small fraction of the percentage of cellulose, an appreciable reduction in the degree of polymerization of the material of the fiber as a whole, which is the weighted average of the degree of polymerization of the cellulose component and the degree of polymerization of the hemicellulose component, will definitely indicate a reduction in the degree of polymerization of the cellulose component.

Now if the degree of polymerization of the cellulose component of the pulp is reduced,* the paper made from it will be weaker, because of loss of intrinsic strength of the fiber. This concept will perhaps explain some of the changes in the papermaking properties of the fiber brought about by variations in the pulping treatment. For example, referring again to the bleached sulphate pulp and the holocellulose extracted with 4% caustic potash in March's experiments, although both possessed the same alkali-extractable hemicellulose content (12.5%), the former had a D.P. of 1000 and the latter a D.P. of 1120, and the bursting strengths of the two pulps were 117 and 149, respectively.

Whether this difference in D.P. is sufficient to account completely for the 28% difference in bursting strength or whether Ross's third possibility—i.e., modification of the physical structure of the fiber itself—is also brought into play, is a matter for further investigation. Nevertheless, it would appear to be a reasonable hypothesis to say that, at the same hemicellulose content, the fibrous material with the highest D.P. should give the strongest paper. At different hemicellulose contents, as we have already explained when reviewing the work of Jayme and Lochmüller-Kerler, the strength would be a compromise between degree of polymerization, which determines intrinsic fiber strength as well as bonding strength, and hemicellulose content, which determines plasticity and, consequently, fiber-bonding area. It would have been interesting if the degree of polymerization of the pulps produced by Hart and Strapp had been determined to check the foregoing hypothesis.

* According to Jayme, there is an upper limit of D.P. of about 1100 to 1400, above which increase of strength is little and below which decrease of strength becomes more and more noticeable.

## PAPERMAKING CONSIDERATIONS

In all the foregoing we have been considering the fibers of wood pulps. It is desirable at this point, however, to relate our conclusions to papermaking phenomena in general. For this purpose, one of the things we must do is to see how these conclusions fit in with the behavior of rag pulps.

Now rag pulps contain well over 90% of normal cellulose and no hemicellulose. A typical analysis of a papermaking cotton rag pulp, from shirt cuttings, is given in Table IV.

**Table IV**

| | |
|---|---|
| Alpha-cellulose | 97.2 |
| Beta-cellulose | 0.1 |
| Gamma-cellulose | 2.7 |
| Copper number | 1.09 |

The small amount of gamma-cellulose can be assumed to consist wholly of cellulose degradation products and not to any natural hemicellulose.

Nevertheless, in spite of the absence of hemicellulose in rag pulps, papers of quite considerable strength can be made from this material, although it should be pointed out that, when the strength of rag paper is referred to, it is usually tearing and folding strengths which are thought of and not tensile or burst. Actually, from the point of view of bursting and tensile strength, rag papers are not exceptionally strong. Moreover, commercial rag papers are invariably tub sized, which can add 100% or more to their bursting and tensile strengths, and quite appreciably to the folding strength. In Table V are shown the bursting and tearing strengths of laboratory sheets made from stuff

**Table V**

| | *Canadian freeness* | *Burst ratio* | *Tear ratio* |
|---|---|---|---|
| New white cuttings | 30 | 1.51 | 1.56 |
| Bleached cotton rag | 74 | 1.11 | 1.03 |
| Cotton rag (shirt cuttings) | 70 | 1.43 | 1.50 |
| Scandinavian bleached kraft | 300 | 2.12 | 1.00 |
| Scandinavian strong bleached sulphite | 300 | 1.5 | 0.75 |
| Scandinavian medium bleached sulphite | 300 | 1.2 | 0.65 |
| Scandinavian soft bleached sulphite | 300 | 0.9 | 0.50 |

obtained from three rag paper mills, which were prepared for making strong papers. These laboratory sheets were, of course, waterleaf and, thus, the complicating effect of tub sizing has been avoided. In this table for comparison are also shown the corresponding strengths for strong bleached kraft, strong bleached sulphite, and medium and soft bleached sulphites.

**Table VI. Rag Pulp**

| Beating time, hr. | Canadian freeness, ml. | Sheets dried from water: Shrinkage, % | Burst ratio | Tear ratio | Standard bulk | Double folds | Opacity (contrast ratio) | Sheets dried from alcohol: Shrinkage, % | Burst ratio | Tear ratio | Standard bulk | Double folds | Opacity (contrast ratio) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.5 | 343 | 3 | 1.14 | 2.38 | 1.70 | 1076 | 89.2 | Nil | 0.50 | 1.17 | 2.12 | 4.8 | 99.1 |
| 2.0 | 137 | 5 | 1.35 | 2.08 | 1.62 | 2040 | 92.5 | Nil | 0.46 | 0.95 | 2.12 | 5.7 | 99.6 |
| 2.5 | 62 | 6 | 1.35 | 1.63 | 1.43 | 2052 | 92.2 | Nil | 0.43 | 0.70 | 2.03 | 7.2 | 99.7 |
| 3.0 | 22 | 7 | 1.40 | 1.33 | 1.25 | 3289 | 90.0 | Nil | 0.38 | 0.50 | 2.02 | 5.8 | 99.9 |
| 3.5[a] | 13 | 12 | 1.41 | 1.15 | 1.26 | 1442 | 85.4 | Nil | 0.34 | 0.33 | 2.01 | 5.0 | 99.9 |
| 4.0[a] | 0 | 12.5 | 1.39 | 1.10 | 1.15 | 1041 | 74.2 | Nil | 0.33 | 0.30 | 2.09 | 4.0 | 99.6 |
| 4.5[a] | −52 | 13 | 1.28 | 0.73 | 1.07 | 468 | 70.7 | Nil | 0.29 | 0.21 | 2.12 | 2.5 | 99.9 |

[a] The sheets were greaseproof after 3½ hr. beating. None of the sheets dried from alcohol were greaseproof.

Tearing strength is chiefly a function of fiber length, so that it is not surprising that rag pulps exhibit a good tearing strength, but bursting strengths of the order of strong bleached sulphite obtained from pulps containing no hemicellulose require to be explained in view of the hypothesis which has been advanced as to the function of hemicelluloses in the papermaking qualities and strength of wood pulps.

Rags, before they can be made into paper possessing any degree of strength, require first considerable processing in the breaker, during which time the fibers are not only unraveled from the fabric but also become fibrillated to no small degree. They then have to be beaten for quite an appreciable time, during which they become coarsely but very considerably fibrillated. This is illustrated in the above table, for it will be noted that, whereas the wood pulps have attained their maximum or almost maximum strength by the time they reach a Canadian freeness of 300, the Canadian freeness of all the rag pulps is well below 100, a degree of wetness which in a sulphite wood pulp would render it almost greaseproof. This effect is further illustrated in photomicrographs 3A and 3B, showing rag and wood pulp fibers beaten to 137 and 215 C.F., respectively—i.e., to a degree suitable for a medium weight bond paper. The much greater amount of shredding of the rag fibers is very apparent. These two samples were beaten in the same beater in the same way for 2 hours and 0.5 hour, respectively. The much greater treatment it is necessary to give rag pulp to make ordinary strong paper, as compared with wood pulp, is not only denoted by the lower freeness of the beaten stuff but also by the much longer time of beating. The usual time of beating given to a rag paper would bring a bleached sulphite to the greaseproof stage. It appears, therefore, that rag pulp must be processed much more than wood pulp to obtain the degree of fiber-to-fiber bonding required to produce a strong paper. This is illustrated by the fact that, whereas sulphite wood pulp need only be to 60 beaten to 70 C.F. and kraft to 40 to 50 C.F. to reach greaseproof stage, even a very strong rag pulp has to be beaten to nearly zero (Canadian freeness) before it becomes greaseproof, and weaker rags have to be beaten considerably more before they become greaseproof.

Now, as we have indicated previously, an idea of the change in the degree of fiber-to-fiber bonding may be derived from the change in opacity of the paper made from the pulp. Tables VI and VII show the changes with beating in the strength and opacities of a rag pulp (new cotton dry-felt cuttings) and a strong air-dry bleached sulphite wood pulp. The data in the left hand columns of Tables VI and VII under the heading "Sheets dried from water" refer to laboratory sheets made in the normal manner. The changes in opacity with beating of these normally made sheets are shown under the column "Contrast ratio" and, as in the case of the data in Table I, all the opacity figures are calculated to a sheet basis weight of 85 grams per square meter.

It will be seen from the figures in Table VI that, until a freeness below 22 C.F. is reached, the opacity of the rag pulp changes very little. This does not necessarily mean that no fiber-to-fiber bonding has taken place

**Table VII. Strong Bleached Sulphite Wood Pulp**

| Beating time, hr. | Canadian freeness, ml. | Sheets dried from water: Shrinkage, % | Burst ratio | Tear ratio | Standard bulk | Double folds | Opacity (contrast ratio) | Sheets dried from alcohol: Shrinkage, % | Burst ratio | Tear ratio | Standard bulk | Double folds | Opacity (contrast ratio) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Unbeaten | 680 | 1.5 | 0.39 | 0.64 | 1.81 | 3.7 | 84.2 | 0.5 | 0.12 | 0.17 | 2.01 | 0 | 86.4 |
| 0.25 | 396 | 3 | 1.42 | 0.80 | 1.46 | 273 | 79.0 | 1.0 | 0.46 | 0.56 | 1.75 | 6.2 | 86.5 |
| 0.50 | 215 | 4 | 1.69 | 0.79 | 1.37 | 360 | 75.0 | 1.5 | 0.63 | 0.64 | 1.70 | 22.7 | 86.4 |
| 0.75 | 100 | 5.5 | 1.77 | 0.72 | 1.29 | 423 | 70.8 | 2.0 | 0.70 | 0.62 | 1.69 | 59.0 | 86.0 |
| 1.00[a] | 44 | 6 | 1.80 | 0.68 | 1.32 | 538 | 64 | 2.5 | 0.70 | 0.60 | 1.63 | 59.0 | 84.9 |
| 1.25[a] | 20 | 9 | 1.80 | 0.63 | 1.27 | 557 | 56 | 2.5 | 0.70 | 0.60 | 1.61 | 61.0 | 84.3 |
| 1.50[a] | 8 | 10 | 1.70 | 0.56 | 1.20 | 574 | 49 | 2.5 | 0.72 | 0.55 | 1.60 | 59.0 | 83.0 |
| 1.75[a] | −14 | 10 | 1.67 | 0.52 | 1.11 | 356 | 43 | 2.5 | 0.68 | 0.46 | 1.52 | 28.2 | 80.8 |

[a] Sheets were greaseproof after 1 hr. beating. None of the sheets dried from alcohol were greaseproof.

until a freeness of below 22 has been reached, but means that the increase in fiber-to-fiber bonding with beating up to this point is relatively small, and only sufficient to keep pace with the increase in reflecting and refracting surfaces brought about by fibrillation. (The small increase in opacity from 1.5-hours to 2-hours beating was probably due to the fiber length still being so long after 1.5 hours' beating that the stuff was still too clotty to make a uniform sheet, even at the high dilution in the laboratory sheet machine). The wood pulp, on the other hand (Table VII), shows considerable opacity decrease from the start of the beating, indicating that bonding is rapidly increasing right from the commencement.

In the left-hand columns of Table VI and VII, under the heading of "Sheets dried from alcohol," are given similar data on these two pulps when the fibers of the laboratory sheets made from the pulps beaten to different degrees were substantially prevented from bonding. This was effected by steeping the sheets, after couching and pressing in the normal way but before drying, in industrial alcohol. The sheets were steeped overnight in this way, then they were transferred to a fresh lot of alcohol, and steeped a second time for several hours. In this way the water originally present in the sheets was practically wholly displaced by alcohol. The sheets were then dried at 60°C. in the usual way.

The data obtained on these sheets show the effect of substantially eliminating the bonding between the fibers. The bursting strength is reduced to a half or less, tearing strength similarly, and shrinkage is practically eliminated but, most interesting of all, when bonding is substantially prevented, the opacity increases slightly with beating. This, of course, is due to the fibrillation increasing the reflecting and refracting surfaces which, in the presence of water, would immediately be more than counteracted by increased bonding, but in the presence of alcohol, where bonding is either completely or largely prevented, this latter effect is eliminated. The difference between the contrast ratios of the sheets dried from alcohol and the sheets dried from water would appear to give a measure of the extent of the bonding of the fibers in the sheet.

The foregoing results show the great difference in the behavior of rag pulp and wood pulp on beating. Wood pulp is naturally plasticized by the hemicelluloses it contains and this facilitates fiber-to-fiber bonding, which can then be augmented by the beating action. Rag pulp, on the other hand, relies solely on being plasticized mechanically by the beating action and, consequently, requires the latter to be prolonged to a considerable extent before it achieves similar results to those achieved by wood pulp with relatively moderate treatment.

## CONCLUSIONS

This concludes my survey of the information and ideas at present held on the role that hemicelluloses in fibers play in influencing their papermaking properties. There are numerous gaps in our knowledge, and a considerable amount of further evidence is required to substantiate or deny the theories and ideas I have described in this paper.

Referring to the ideas of several investigators, but in particular those of Ross, it would appear that further investigations to determine the changes, not only in the quantities, but also in the nature and compositions of the different hemicelluloses remaining in the pulp after the wood has been treated with various reagents, especially the liquors normally used for pulping, would be very revealing, particularly if these results were related to the papermaking properties of the pulps. It is very desirable, in other words, to extend the work of Hart and Strapp to include an analysis of the nature and the composition of the hemicelluloses in the pulps investigated and the degree of polymerization of these pulps.

It would also, I think, prove of great interest and throw considerable light on the effect of beating different types of pulps, if investigations were undertaken to determine whether different methods of producing pulps caused differences in the proportions of amorphous and crystalline cellulose present, or whether the amounts and kinds of hemicelluloses present have any effect on these proportions, and to relate these to the beating properties of pulps. Rag pulps, which contain no hemicelluloses, should be included in this investigation; the results might throw considerable light on the type of mechanical treatment which is required to treat pulp efficiently and satisfactorily, instead of assuming, as we do at present, that all that is needed is to treat fibers between two moving metal surfaces under pressure.

Several investigators have shown that fibers can be well fibrillated and yet the paper made from them lacks strength whereas, on the other hand, the paper from certain types of stuff may attain a high degree of strength before any fibrillation of the fibers is visible. This is illustrated in the photomicrographs of fibers of Scandinavian kraft and sulphite papers (Figs. 4A and 4B). It is possible that the ideal beating action is a mechanical treatment, which does not fibrillate the fiber, but raises the proportion of amorphous to crystalline cellulose, as has been suggested by Gallay (*15*), and the nature of such mechanical treatment, if practicable, would be of great interest and importance to the paper industry and to the designers of a paper preparation plant.

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# PERSONAL MENTION

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*Howard R. Rickards,* Superintendent of Paper Mill, Doeskin Products, Inc., Wheelwright, Mass.

*Robert C. J. M. Rijssenbeek,* Director, N. V. Papierfabriek Gennep, Gennep, The Netherlands, a 1941 graduate of the University Nijmegen.

*Francis W. Sadler, III,* Analyst, International Paper Co., Bastrop, La., a 1949 graduate of Tulane University.

*Walter A. Salmonson,* Manufacturer's Agent, Portland, Ore.

*Harry J. Shelton,* Vice-President, Gruendler Crusher & Pulverizer Co., St. Louis, Mo., a 1937 graduate of Washington University.

*Kisaburo Shimbo,* Technical Superintendent of Pulp Mill, Nippon Pulp Industry Co. Ltd., Nichinan-shi Miyazaki-ken, Japan, a 1920 graduate of Tokyo Imperial University.

*Bunzo Shimura,* Auditor, The Kokusaku Pulp Industry Co. Ltd., Chuo-Ku, Tokyo, Japan, a 1912 graduate of Tokyo Higher Technical College.

*Fritz Stockigt,* Technical Director, Felix Heinr. Schoeller, Duren Rhineland, Germany, a 1921 graduate of Technische Hochschulen.

*Ryosaku Takata,* President, Tohoku Pulp Co. Ltd., Chiyoda-Ku, Tokyo, Japan, a 1907 graduate of Tokyo Higher Technical School.

*Pekka Vakomies,* Superintendent, Sunila Co., Sunila, Finland, a 1946 graduate of The Technical Institute of Finland.

*J. A. Van den Akker,* Research Associate, The Institute of Paper Chemistry, Appleton, Wis., a 1926 graduate of the California Institute of Technology, with a Ph.D. degree in 1931.

*Alfred C. Webber,* Supervisor of Physics Section, E. I. du Pont de Nemours & Co., Polychemical Dept., Experiment Station, Wilmington, Del., a 1928 graduate of Bates College, with an M.A. degree from Boston University in 1940.

*Toru Yoshitoshi,* Resident Yufutsu Mill Manager, The Kokusaku Pulp Industry Co. Ltd., Chuo-Ku, Tokyo, Japan, a 1919 graduate of the Imperial University, Kyushu.

### *TAPPI Notes*

*John W. Bard,* Chemical Engineer, Marathon Corp., Rothschild, Wis., is on leave of absence from the Company and is taking work in the Business and Administration School of the Mass. Inst. of Technology under the Sloan Fellowship Program.

*Thomas M. Barry* is now Manager of Northern Mills, Hollingsworth & Whitney Co., Waterville, Me.

*Norman I. Bearse* is now Vice-President in charge of Production, Champion-International Co., Lawrence, Mass.

*Robert J. Becker,* formerly student at the N. Y. State College of Forestry is now Chemist for the Riegel Paper Corp., Milford, N. J.

*Richard L. Betts* is now Technical Director, Champion Paper & Fibre Co., Pasadena, Texas.

*Wilson F. Brown,* formerly of Hamilton, Ohio, is now Research Director, Pulp and Paper Laboratories, University of Florida, Gainesville, Fla.

*J. W. Burke* is now in the Technical Sales Dept., Hercules Powder Co., Kalamazoo, Mich.

*Charles F. Carpenter*, formerly of the New York and Pennsylvania Co., is now Consultant and Technical Adviser, White Star Paper Co., Prescott, Ark.

*C. R. P. Cash* is now Resident Manager, Fibreboard Products, Inc., Antioch, Calif.

*Everett W. Clem* is now Vice-President in charge of Engineering, Rice Barton Corp., Worcester, Mass.

*D. Walter Crutchfield*, formerly of Beaumont Mills, Inc., is now Consulting Engineer, Asheville, N. C.

*M. W. Davis* is now President, Sherbrooke Machineries, Ltd., Montreal, P. Q.

*W. H. Graebner* is now Manager of Production, Marathon Corp., Menasha, Wis.

*Robert E. Harper* is now Manager of Operations, Rhinelander Paper Co., Rhinelander, Wis.

*Donald F. Jenkins*, formerly of the N. Y. State College of Forestry, is now junior chemist, Champion Paper & Fibre Co., Hamilton, Ohio.

*Thomas J. Kavanagh*, formerly of the Holyoke Machine Co., is now Design Draftsman, United Aircraft Corp., E. Hartford, Conn.

*William A. Kosicki*, formerly of the Scott Paper Co., is now Plant Engineer Marinette Paper Co., Marinette, Wis.

*Richard D. Lewis* is now Group Leader, Pulping Section, Central Laboratory, St. Regis Paper Co., Deferiet, N. Y.

*James H. McClure* is now Asst. Plant Manager, Sherman Paper Products Co., Newton Upper Falls, Mass.

*Leslie G. McCowan*, formerly of the N. Y. State College of Forestry, is now a trainee at the Sorg Paper Co., Middletown, Ohio.

*Frank Makara*, Patent Attorney and Consultant, is now located at 2451 Webster Ave., Bronx 63, N. Y.

*George R. Marsh*, formerly of C. J. Merrill, Inc., is with the George R. March Co., Portland, Me.

*Thomas F. Martin*, formerly student at the N. Y. State College of Forestry, is now Quality Control Supervisor, Harford City Paper Co., Hartford City, Ind.

*Bernard K. Mayer*, formerly student at the N. Y. State College of Forestry, is now a Research Assistant, Oxford Paper Co., Rumford, Me.

*D. H. Maunsell* is now Mill Manager, Dryden Paper Co., Dryden, Ont.

*Charles A. Morton*, Sales Engineer, West Virginia Pulp & Paper Co., has been transferred from New York to Chicago, Ill.

*John F. Nolan*, formerly of the N. Y. State College of Forestry is now Chemist, Sorg Paper Co., Middletown, Ohio.

*Max R. Oberdorfer* is now Executive Vice-President and General Manager, St. Helens Pulp and Paper Co., St. Helens, Ore. *Max Oberdorfer* because of ill health has resigned as General Manager but will continue as President of the Company.

*R. Paradis*, formerly of the Sorg Paper Co. Ltd., is now Asst. Kraft Mill Superintendent, Brown Co., Berlin, N. H.

*John L. Parsons* is now Technical Director, Hollingsworth & Whitney Co., Waterville, Me.

*Carl E. Price*, formerly Ball Bros Co., is now Research Engineer, Albany Felt Co., Albany, N. Y.

*Daniel F. Quirk* is now President, Peninsular Paper Co., Ypsilanti, Mich.

*Reuben B. Robertson, Sr.*, is now Chairman of the Board, Champion Paper & Fibre Co., Canton, N. C.

*Charles R. Seaborne* is now Executive Vice-President, Thilmany Pulp & Paper Co., Kaukauna, Wis.

*Daniel T. Snell*, Research Chemical Engineer, Robert Gair Co. Inc., Uncasville, Conn. has left for military service. His home is in Portland, Me.

*Claude M. Stitt* is now Head of the Central Engineering Dept., Fiberboard Products, Inc., Antioch, Calif.

*Robert I. Thieme* is now Technical Director, Soundview Pulp Co., Everett, Wash.

*Robert J. Van Nostrand* is now in the Pulp Sales Div., Brown Co., Chicago, Ill.

*Charles R. Ward, Jr.*, formerly of the N. Y. State College of Forestry is now Chemist, Champion Paper & Fibre Co., Canton, N. C.

*Allen W. Wiegand*, formerly of the School of Forestry, University of California is now in the Advanced Signal Officers Course, The Signal School, Fort Monmouth, N. J.

*Frederick Wierk*, Consulting Engineer, has established his office at 220 East 42nd Street, New York 17, N. Y. (Mu 2-8598).

* * *

*Clarence Larson*, Vice-President in charge of Production, Minnesota and Ontario Paper Co., International Falls, Minn., has succeeded Donald D. Davis as the official corporate representative of the Company in the Technical Association.

*Vance P. Edwardes*, Consultant, Corinth, N. Y., *K. O. Elderkin*, Crossett Paper Mills, Crossett, Ark., and *James J. Harrison*, Michigan Carton Co., Battle Creek, Mich., recently constituted a task force for the Economic Cooperation Administration in Austria. They studied the needs of the pulp and paper mills in that Country.

## *Industry Notes*

Paper and allied products, lumber and wood products, and printing, publishing and allied products are industry groups included in the list of essential activities prepared by the Department of Commerce for guidance of Department of Defense occupations. Reservists in the pulp and paper industry are being considered on an individual basis. Initial deferments will be reviewed. Applications for delay in call to active duty should be made when the reservist receives his call to active duty, and should be made in writing. The request made by the reservist or his employer.

* * *

The J. O. Ross Engineering Corp., has removed its offices to 444 Madison Ave., New York, N. Y.

* * *

The American Forest Products Industries, Inc., 1319 Eighteenth St., N. W., Washington 6, D. C., has issued a leaflet on "The American Tree System."

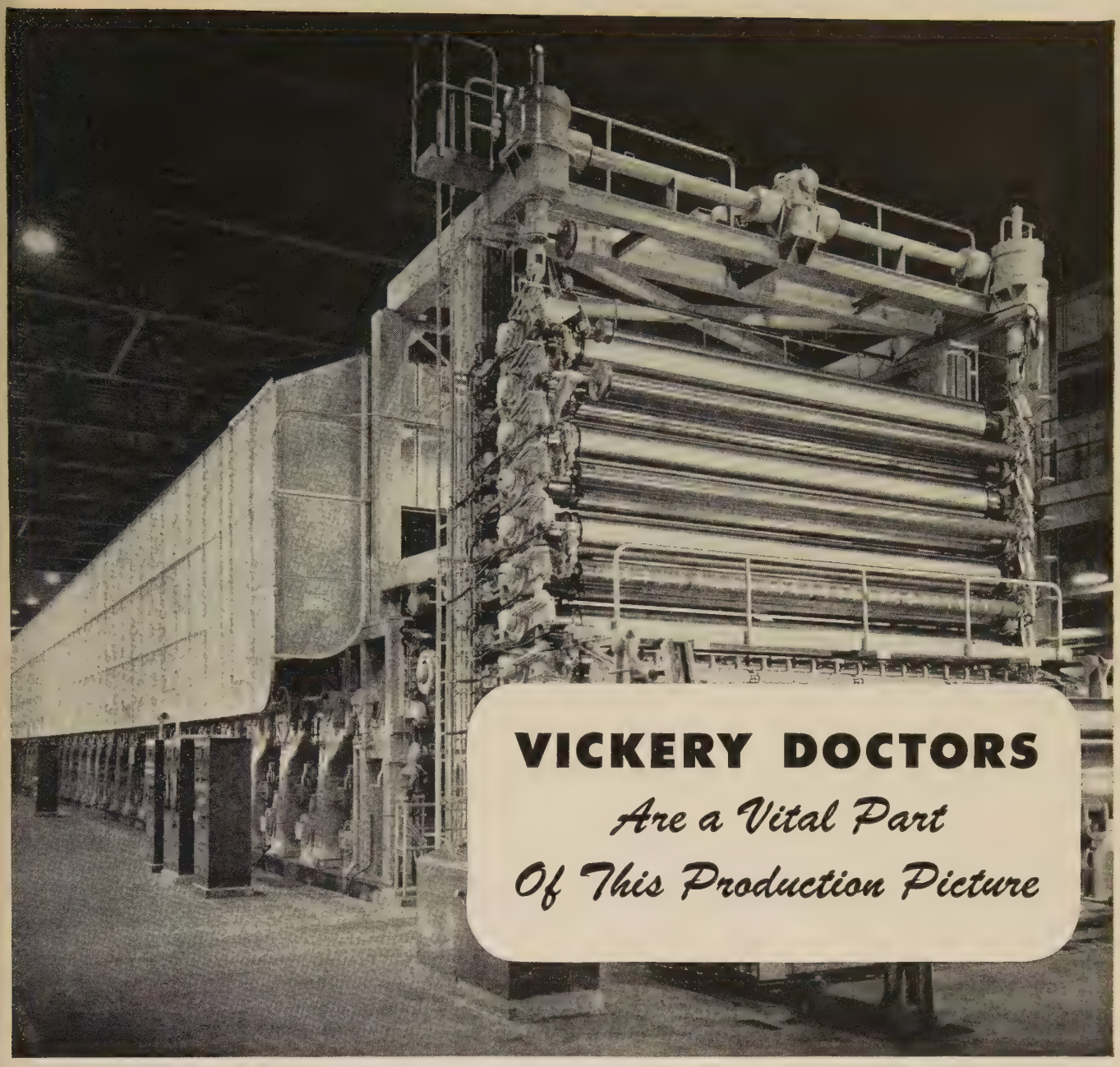
* * *

The Atlas Mineral Products Co., Mertztown, Pa., announces the following changes in personnel: Richard W. Weppner has been appointed sales engineer for corrosion-resistant chemical construction materials in Delaware, Maryland, Virginia, West Virginia, and New Jersey; Philip E. Berens has been appointed sales representative in Eastern Pennsylvania, Western New York, and parts of New Jersey; William A. Streaker has been appointed sales engineer for Lower Michigan, Eastern Indiana, and Lucas County, Ohio.

The Atlas Mineral Products Co., has just issued its new General Bulletin MCC No. 1. This describes the Company's line of corrosion-proof linings, cements, brick and tile, etc.

* * *

The Oswego Falls Corp., Fulton, N. Y., has installed the Vortrap System for cleaning groundwood stock. This installation is made up of two 10-inch primary and one 4-inch secondary Vortraps, designated to handle stock at 0.75% consistency. The Vortraps are installed immediately after the bull screens, the plates of which have $^3/_8$-inch holes. The accepted stock from the Vortrap passes through conventional screening equipment and then to the wet machines. Foreign material rejected in the 10-inch primary units is bled




Every one of the shining calender rolls in this giant stack are equipped with Vickery Doctors — and the dryers back of them, too.

Vickery Doctors represent a tiny fraction of the investment in this or any paper machine but they are a big factor in its ability to operate with continuous efficiency and economy. On calender rolls they operate continuously, hugging every inch of the roll, keeping the sheet free of calender marks and guarding against breaks.

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out of the top of the waste receiver, diluted with white water and further treated in the 4-inch secondary Vortrap. Foreign material rejected in this unit is bled off continuously to the sewer.

* * *

George H. McBride has been appointed Manager of the Gearing Division, Westinghouse Electric Corp., Pittsburgh, Pa.

* * *

The Committee for Economic Development, 444 Madison Ave., New York 22, N. Y., has issued a bulletin on "How to Raise Real Wages." It is recommended for distribution to company employees.

* * *

A. E. Staley Manufacturing Co., anounces that its new solvent extraction plant for soybeans will replace the Company's remaining expeller capacity and will begin operation this fall.

* * *

The Armstrong Machine Works, Three Rivers, Mich., has issued a bulletin describing the inverted bucket steam traps for paper-machine driers. It is entitled "Are Steam Traps Practical for Draining Paper-Machine Driers?"

* * *

Stadler, Hunter & Co., 609 Drummond Bldg., Montreal 2, P. Q., has issued a leaflet describing its new roll-wrapping machine. A considerable saving in labor costs is claimed.

* * *

The De Laval Steam Turbine Co., Trenton 2, N. J., has just issued a new 32-page bulletin No. G-WBV on the IMD De Laval Worm Gear Speed Reducers.

* * *

The Packaging Institute, New York, N. Y., has issued its new manual of paper testing procedures. These correspond to the TAPPI procedures of the same titles.

* * *

The Railway Supply & Mfg. Co., Cincinnati, Ohio has appointed James T. Flannery Co., 26 Journal Sq., Jersey City 6, N. J. as Eastern Sales representative to the paper and plastics fields. Mr. Flannery has been extremely active in this field for many years, and is, at present, President of the National Association of Waste Materials Dealers. The Railway Supply & Mfg. Co. has long been engaged in the research and development of cotton linters and cotton fibers.

* * *

The general offices of Infilco, Inc., are now located at 2750 South 12th Street, Tucson, Arizona. The quarters vacated at 325 W. 25th Place, Chicago, Ill., will continue to be used by the laboratories, advertising, and parts of the engineering department.

* * *

Forest B. Evans has been named assistant to the General Manager of the Virginia Cellulose Dept., Hercules Powder Co., Wilmington, Del. He is being succeeded as plant manager of the Virginia Cellulose plant at Hopewell, Va., by Orval J. Hand.

* * *

The Link-Belt Co., 307 N. Michigan Ave., Chicago 1, Ill., has issued a new 88-page book No. 2274 on its P.I.V. Drive.

* * *

A new chemically inert diaphragm for the Grinnell-Saunders diaphragm valves has been announced by the Grinnell Co. Inc., Providence, R. I. This thermoplastic (KEL-F) has been successfully molded to form a tough, flexible diaphragm for use with corrosive liquids.

* * *

The Sherman Paper Products Co., will open a new plant this fall at 2245 W. Pershing Road, Chicago, Ill, to make flexible corrugated papers.

* * *

E. D. Beachler has been appointed Chief Engineer of the Beloit Iron Works, Beloit, Wis.

* * *

Forest Products Laboratory Employees Association, North Walnut St., Madison, Wis., has issued an interesting 36-page booklet entitled "Toward Wiser Use of Wood."

# OBITUARIES

### Edward A. Shallcross, Sr.

Edward Alexander Shallcross, Sr., Consulting Pulp and Paper Mill Chemical Engineer died at Frankford, Philadelphia, Pa., on July 16, 1950.

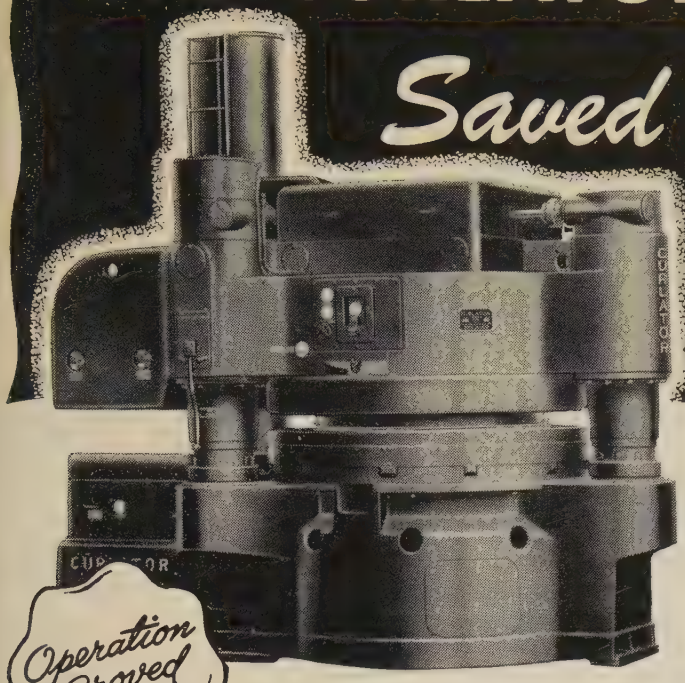
Mr. Shallcross was born at Frankford on Dec. 10, 1885 and graduated from Drexel Institute in 1908. He devoted most of his lifetime since leaving Drexel to inventions and engineering developments. Although he worked independently during most of this period he was associated for brief periods with Richards-Wilcox Mfg. Co., F. W. Tunnell Co., Kali Mfg. Co., and recently with Sharpless Chemical Co. He became a member of TAPPI in 1943.

### James C. Lowe

James C. Lowe, Sales Engineer for Oliver United Filters Inc., Chicago, Ill. died on July 9 from injuries sustained in an automobile accident several days earlier.

Mr. Lowe was born at San Antonio, Texas on Oct. 12, 1913. From 1933 to 1937 he served on the U. S. Texas in the U. S. Navy. From 1937–1944 he was a field engineer for the Permutit Co. in New York. In 1944–1945 he was with the Sinclair Rubber Co. at Houston, Texas and joined the Oliver United Filters sales organization in 1945 where he specialized in the engineering and sales of filters to the pulp and paper industry.

# One CURLATOR in one year Saved 6,500 CORDS OF PULPWOOD IN A NEWSPRINT MILL



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Curlators now in commercial operation on newsprint sulphite have paid for themselves in only a few months. The mill referred to increased its yield and maintained its quality standards while making these remarkable savings.

The many thousands of dollars that curlation saved in this mill can also be saved in most newsprint mills.

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I would like to be shown how Curlator can make similar savings for me.

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## *TAPPI Paper-Plastics Conference*

The Plastics Committee will sponsor a Paper-Plastics Conference to be held in Marshall Hall, New York State College of Forestry, Syracuse, N. Y., on Oct. 19–20, 1950. E. C. Jahn will be General Chairman and announces the following program:

***Thursday Morning, October 19, 9:30 a.m.***

I. Properties of Plastics in Relation to Papermaking

*Discussion Leader—Herman Mark, Polytechnic Institute of Brooklyn*

1. "New Polymers and Their Possible Application to Paper," by Herman Mark, Polytechnic Institute of Brooklyn.
2. "Adhesion Fundamentals," by D. B. Hatcher, Plaskon Division, Libby-Owens-Ford Glass Co.
3. "Permeability of Polymers to Vapors," by A. D. McLaren, Polytechnic Institute of Brooklyn.
4. "Effect of Plasticizers on Physical Properties of High Polymers," by R. S. Boyer, The Dow Chemical Co.

***Lunch—Drumlins, 12:30 p.m.***

***Thursday Afternoon, October 19, 2:00 p.m.***

II. Beater Addition Fundamentals

*Session Chairman—C. E. Libby, New York State College of Forestry*

*Discussion Leader—Allan Schenck, Riegel Paper Corp.*

1. "The Effect of Latex Variables in Beater Addition of Nitrile Latices," by D. M. Yost, Sorg Paper Co. and William H. Aiken, The Goodyear Tire and Rubber Co.
2. "The Effect of Certain Papermaking Variables in Beater Addition of Nitrile Latices," by D. M. Yost, Sorg Paper Co. and William H. Aiken, The Goodyear Tire and Rubber Co.
3. "Phenolic Resins in Paper Modified by Acrylonitrile Rubbers," by R. C. Bascom, B. F Goodrich Chemical Co.
4. "Headbox Chemistry," by V. J. Moser and I. J. Gruntfest, Rohm and Haas Co.

***Friday Morning, October 20, 9:30 a.m.***

III. Cellulose—Accessibility, Reactivity and Properties relating to Plastics

*Session Chairman—F. A. Simmonds, U. S. Forest Products Laboratory*

*Discussion Leader—John A. Howsman, American Viscose Corp.*

1. "The Accessibility of Cellulose" by Harold Tarkow, U. S. Forest Products Laboratory.
2. "Kinetics and Equilibria in Cellulose Reactions," by H. M. Spurlin, Hercules Powder Co.
3. "Pulp Property Requirements for Dissolving Pulps," by Robert H. MacClaren, Eastman Kodak Co., Rochester N. Y.
4. Other papers to be announced.

***Lunch—Drumlins, 12:30 p.m.***

***Friday Afternoon, October 20, 2:00 p.m.***

IV. Plastic Coating Fundamentals

*Session Chairman—R. T. Nazzaro, New York State College of Forestry*

*Discussion Leader—R. H. Kienle, American Cyanamid Co.*

1. "Alathon Polythene Coatings—Properties and Techniques," by Alfred Stockfleth, E. I. duPont de Nemours & Co.
2. "The Effect of Compounding Variables on Styrene-Butadiene Latex Used for Protective Coatings for Paper," by M. E. Wendt and William H. Aiken, The Goodyear Tire and Rubber Company.
3. "The Technology of Styrene Latex Paper Coating," by Eli A. Haddad, Monsanto Chemical Co.
4. "The Versatile Vinyl Enters the Paper Coating Field," by A. L. Hatfield, B. F. Goodrich Chemical Co.

Hotel Reservations—Hotel Onondaga and Hotel Syracuse each have reserved rooms for the Conference. Please mention the Paper-Plastics Conference when you request Hotel reservations. Other hotels include the Mizpah Hotel and the Jefferson-Clinton Hotel.

## *Alkaline Pulping Conference*

The Alkaline Pulping Conference will be held at the George Washington Hotel, Jacksonville, Fla., October 24–27, 1950. Room reservations should be made with the TAPPI Housing Committee, Jacksonville Convention and Tourist Bureau, 307 Hogan St., Jacksonville 2, Fla. Following is the tentative program:

***Meeting of Wednesday, October 25***

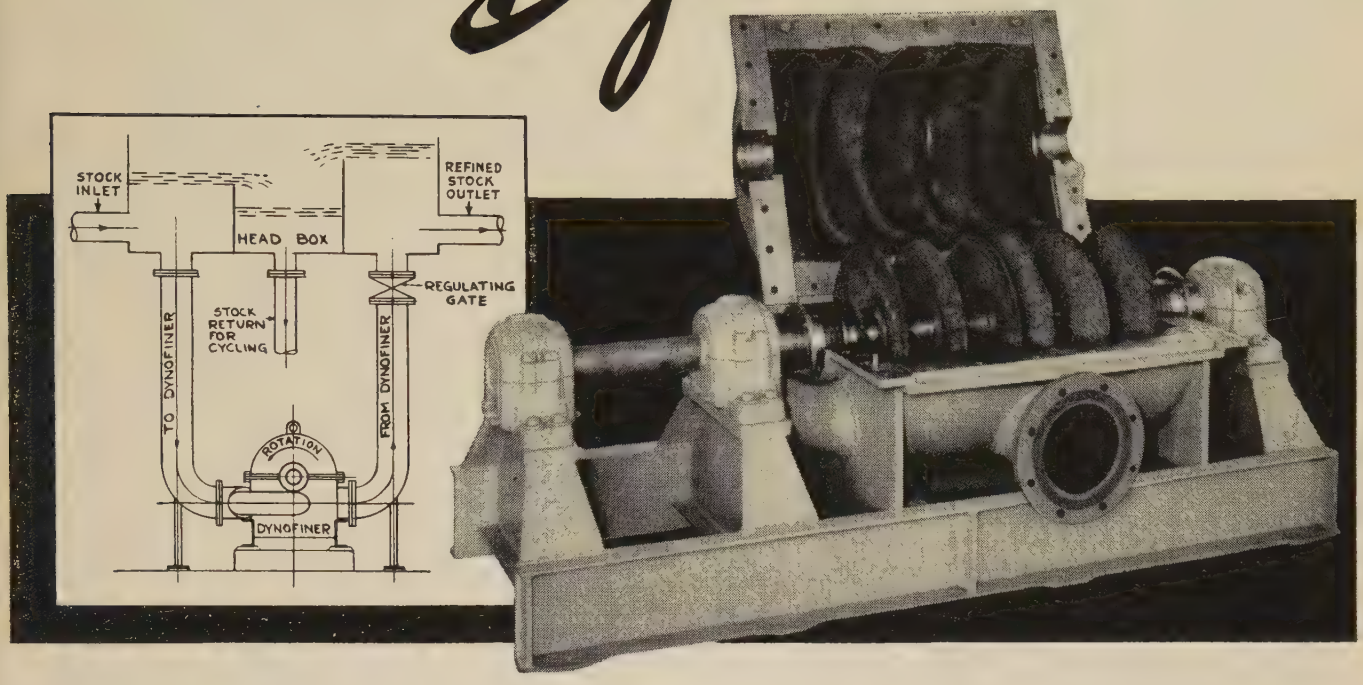
9:30 a.m. Symposium on Causticization

1. "Review of the Literature" by R. R. Fuller, Gulf States Paper Co., Tuscaloosa, Ala.
2. Causticizing of Sodium Carbonate Solutions.
3. "Effect of Sulphidity," by Milton Roberts, Hudson Pulp and Paper Co., Palatka, Fla.
4. "Hydrogen Sulphide and Its Application in Sulphidity Control," by L. B. Taylor, Pittsburgh Plate Glass Co., Pittsburgh, Pa.
5. Causticizing Equipment.
6. Panel Discussion on Causticizing—Representation for equipment, analysis, operation, management, and corrosion: The Panel on Causticizing will be made up of: J. M. Kahn, Infilco Inc., Chicago, Ill., W. B. Gery, Dorr Co., Stamford, Conn., P. B. Borlew, Container Corp. of America, Fernandina, Fla., W. M. Ebersole, Macon Kraft Corp., Macon, Ga., and R. A. Stevens, National Container Corp., Jacksonville, Fla.

2:00 p.m. Symposium on Lime Burning

1. Review of the Literature on Lime Burning.
2. "Selecting the Rotary Kiln for the Lime Recovery Plant," by Ralph E. Gibbs, York, Pa.
3. "The Bird Centrifuge for Sludge Washing and Thickening," by Robert Bowen, North Carolina Pulp Co., Plymouth, N. C.
4. Panel Discussion of Kiln Operation: The Panel on Lime Kilns will be made up of the following: R. S. Walker, Traylor Engineering Co., Allentown, Pa., T. C. Johnson, Union Bag & Paper Corp., Savannah, Ga., and J. E. Bramlett, Champion Paper & Fibre Co., Canton, N. C.

# The Rice Barton DynoFiner




## has no equal for the continuous defibering of slushed paper stock

The efficient, continuous defibering of slushed pulp and waste paper is made possible with the DynoFiner through the use of a series of DynoPellers. These are concave discs. The concave and convex sides are lined with numerous pieces of hard carbide particles. Centrifugal force causes the pulp to be sucked and thrown against the carbides. This effective dynamizing action continuously defibers the stock, the fibres being completely separated one from the other.

If you want to make better pulp from a given grade of stock and make it cheaper, write today for further information on DynoFiners, for continuous operation—DynoPulpers, for batch operation.

### Other DynoMachines:

- The **QuatroPulper** is designed for processing stock in large capacities . . . either batch or continuous operation.
- The **DynoChest** is primarily for disintegrating stock in slush form . . . batch operation.
- The **DynoFiner** is for performing the same operation on a continuous basis.

### The DynoPeller

is the heart of all DynoMachines. Its concave face is lined with rough, hard carbide particles. As the DynoPeller rotates it causes a suction at its center that pulls the stock towards it. Centrifugal force then causes the stock to flow rapidly over the rough carbide particles. This effective dynomizing action completely disintegrates the stock . . . separating each fibre from its neighbor while maintaining its original length.

*Write for complete information*

RICE BARTON Research Corporation
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***Meeting of Thursday, October 26***

9:30 a.m. General Session

1. "Pressure Washing of Kraft Pulp," by Erik Zimmerman and Henry Vranian, The Chesapeake Corp. of Va., West Point, Va.
2. "The Effect of Wood Storage on Yield and Quality," by W. F. Gillespie, Gaylord Container Corp., Bogalusa, La.
3. "Cooking at Constant Temperature and Constant Pressure." (Representative of the University of Florida.)
4. "A New Condenser for Digester Gas-off," by K. W. Coons, University of Alabama, Tuscaloosa, Ala.
5. "How to Design Charts to Compensate for the Effect of Chip Moisture Variations."

2:00 p.m. General Session

1. "Reuse of Water in Kraft Pulp and Paper Mills," by A. E. Drew, Southland Paper Mills, Lufkin, Tex.
2. "Sulphate Pulp Mill Design for Abatement of Odor and Effluent Nuisance," by W. O. Hisey, South African Pulp and Paper Industries, Ltd., Johannesburg, South Africa.
3. "Wet Strength Resin Usage," by R. E. Carter, Reichhold Chemicals Inc., Detroit, Mich.
4. Problems of White Water Reuse from Standpoint of Size, Alum, and Wax Size Utilization.
5. Meeting of the Alkaline Pulping Committee.

***Program of Friday, October 27***

Visit to the University of Florida, Gainesville, Fla., and Hudson Pulp and Paper Co. mill at Palatka, Fla.

## *Fly Ash*

The problem of fly-ash disposal was the subject of a symposium at the 70th Annual Meeting of The American Society of Mechanical Engineers, which was held in New York on November 30. It is estimated that there is about three million tons of fly ash produced annually, and the cost of disposing of it averages 66¢ per ton for utilities, 85¢ per ton for industrials, and the weighted average is 67¢ per ton. If it were impossible to make commercial use of any of this fly ash, the annual bill for its disposal would be about two million dollars. This, incidentally, probably exceeds by several hundred thousand dollars the total budget for all municipal atmospheric-control programs in the United States.

Fly ash may be defined as that part of the ash in the coal that ordinarily goes out the stack. It is emitted in significant quantities only by pulverized-fuel and spreader-stoker plants.

Several public utilities, including the Detroit Edison Company, the Commonwealth Edison Company of Chicago, the Philadelphia Electric Company, and others have done extensive research on the use of fly ash for various purposes. About 20 years ago it was shown that several types of fly ash made a valuable addition to concrete by giving it increased strength; by reducing the heating of concrete in large masses, such as dams; by increasing the resistance to freezing and thawing; and by giving it better workability. The addition of fly ash to concrete also naturally reduces the cost, as fly ash is much cheaper than Portland cement.

The effect of adding fly ash to concrete is called a "Pozzolanic" effect, so named because volcanic ash was so used in the town of Pozzuoli, in Italy, about 2000 years ago. Some structures made then with volcanic ash and lime, rather than with cement, are still standing. Recently-built walls and roads containing as much as 60% of fly ash in place of Portland cement have withstood weather and use for as much as 12 years, and are still in excellent condition.

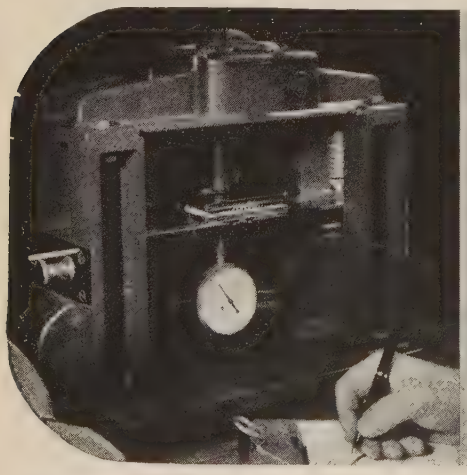
The U. S. Bureau of Reclamation is using fly ash from Chicago in the construction of the Hungry Horse Dam, in Montana, which will be the fourth largest dam in the world. It will require 140,000 tons of fly ash, and 3 million cubic yards of concrete, and the use of fly ash in the concrete will save $1^1/_2$ million dollars in the cost of the dam. There is no doubt that this is merely a forerunner of wider use of fly ash in some types of concrete work. Walter Handy, one of the speakers at the symposium, pointed out that if only 10% of fly ash had been used in cement in the eastern half of the United States, it would have consumed all of the fly ash produced in the country.

Another successful use of fly ash is in the bitumastic road industry, where it has been shown that fly ash from the Detroit Edison Company has properties very similar to the Trinidad asphalt filler used previously. Detroit Edison has given extensive help to road builders in using fly ash, and sold in 1948 alone 31,200 tons for this purpose. No doubt in areas where other fillers are not readily available at low prices this will be an important use for fly ash.

M. C. Randall, of the Philadelphia Electric Company, gave other uses which can be made of fly ash, such as using it in insulating cement; in making building brick, where it is combined with slag from slag-tap furnaces; and in the foundry industry, where it is used for cores, and to some extent as molding sand.

In the field of soil stabilization, for the base courses on roads, for surfacing parking lots, etc., a mixture of limestone screenings and fly ash in a small amount of hydrated lime has been successfully used. The product has been named "Cor Crete," and it is felt that it should run in cost about the same as crushed stone, but will have many of the characteristics of lean concrete, including a smooth and reasonably dustless surface. This use alone would require stupendous amounts of fly ash, if it were approved for use in the building of state highways, etc.

From Appalachian Coals, Inc. Bulletin X, No. 50.

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**TO CONTROL QUALITY OF PRODUCT—A practical, heavy duty instrument for ring stiffness tests of liner-board and box-boards and flat crush tests of combined corrugated board. Measurements uniformly accurate. Recording mechanism independent of machine elements, eliminating friction; plunger and plate free of lateral movement.**

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More than 20 years have glided by since Nopco developed the first chemical defoamer for the pulp and paper industries.

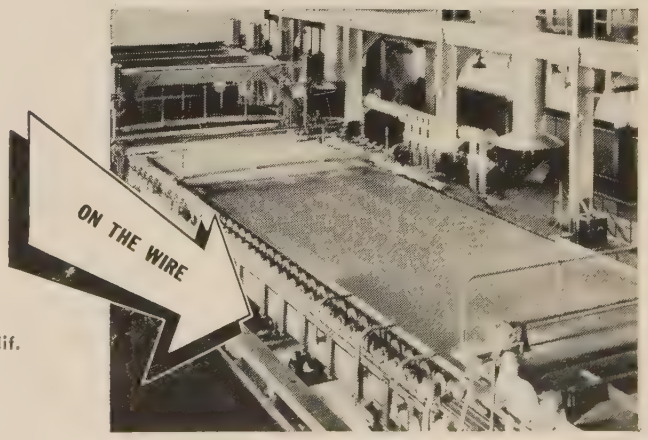
Today, that fact is still your best guarantee of Nopco defoamer superiority. Why? From the moment we introduced our pioneer product, we have continued our exhaustive research to effect constant improvements . . . maintaining a standard of quality unequalled in the field.

From the first, on-the-spot mill conditions have received our particular attention. And solving countless specific problems has provided us with a wealth of vital foam-control data that has no counterpart.

Our outstanding laboratory is uniquely equipped with specialized knowledge and exclusive techniques. No effort is spared to provide defoamers with exactly the characteristics desired. The superior performance of a standard product may often be heightened to meet the needs of an individual mill.

Yes, foam control can be a costly problem unless you put it in the hands of specialists. Following the recommendations of any but the expert can lead to losses that may never be recovered.

Our technical know-how, production facilities, and highly trained sales and service personnel have solved defoamer problems for mills throughout the world. Let us train our sights on your foam problem. "Shooting in the dark" does not pay off.

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# TAPPI DIVISIONS AND COMMITTEES

## *Recent Reports of Activities*

### *Fibrous Materials Testing Committee*

Although the Fibrous Materials Testing Committee did not participate in the Testing Division Conference at Rochester it is carrying on an important program of work. It was intended that B. F. Kukachka, Chairman of the Subcommittee on Identification of Woods and Wood Fibers would report on the Congress held at Stockholm, Sweden, this summer. However, since the nature of the Conference program made such a presentation unfeasible it is hoped that Dr. Kukachka will be able to make this report at the annual meeting to be held in February.

The personnel of the Fibrous Materials Testing Committee is as follows:

E. R. Schafer, Forest Products Laboratory, Madison, Wis., *Chairman.*
S. I. Aronovsky, Northern Regional Research Laboratory, Peoria, Ill.
E. G. Ham, John A. Manning Paper Co., Troy, N. Y.
R. N. Hammond, Weyerhaeuser Timber Co., Longview, Wash.
C. E. Hrubesky, Forest Products Laboratory, Madison, Wis.
E. L. Lamb, Oxford Paper Co., Rumford, Me.
B. E. Lauer, University of Colorado, Boulder, Colo.
T. A. Pascoe, Nekoosa Edwards Paper Co., Port Edwards, Wis.

During the past year the Committee completed its revision of T 7 p-45 "Physical Evaluation of Pulp CordWood" under the new title "Weight-Volume Measurements of Pulpwood and Chips."

Parts of the method T 18 m-47 "Specific Gravity and Moisture Content of Pulpwood" were revised.

Committee Project 351 "Species Identification of Wood and Wood Fibers (T 8 sm-40) is being carried on by Dr. B. Francis Kukachka, who is also working on a universal scheme for wood identification which can be made to fit any number of species and expanded or reduced as may be desired without disrupting the entire key. When this key has been developed sufficiently for use in the identification of most pulpwoods it will be submitted to the Committee for consideration as a TAPPI method. Dr. Kukachka, Chairman of the Subcommittee on Method of Identification of Wood and Wood Fibers is Technologist for The Division of Silvicultural Relations, Forest Products Laboratory, Madison, Wis.

Following is a statement by Dr. Kukachka of the nature and scope of the project:

#### *A Universal Scheme for Wood Identification*

"There is, without doubt, a need for a wood identification scheme which would permit the identification of any wood, irrespective of type or country of origin. At the present time identification depends on keys which are limited in scope because they cover only the timbers of a particular region or country. When the country of origin is unknown the task becomes formidable and sometimes impossible. At any rate, the process is time consuming since a number of keys must be tried before success can be achieved. In many cases it is not possible to identify the wood in question because it is not included in the key, which is frequently the case of secondary and lesser known species. No set procedure can be followed under the present status of the field, but is determined largely by the experience and knowledge of the person attempting identification.

"In view of the shortcomings of existing methods, it is highly desirable that a system be developed which would be universal in scope and cover all woody plants. As early as 1938, Mr. Arthur Koehler attempted the rapid identification of woody families, utilizing the International Business Machine card sorter. Information derived from published anatomical descriptions of various families was coded for punching on IBM cards. This system failed since published descriptions for families are too general, and, in addition, anatomical features do not consistently hold for such large categories as the family. The family cards were eventually abandoned and a numerical system employing some thirteen categories was instituted in its place. As data were accumulated under the numerical system, it was found that the number of categories was far too small and that totally unrelated species would carry the same numerical code numbers.

*James d'A. Clark,*
*General Chairman,*
*TAPPI Testing Division*

"Later, a decimal system of 80 principal categories was developed to correspond to the 80 columns on the IBM card. In addition to the anatomical features, which utilize some 50 columns of the card, the remaining columns were allocated to such features as country of origin, family number, genus number, and various chemical and physical properties, and geographic areas. Each column representing a certain characteristic can be further subdivided into 10 more descriptive units. For example, pore arrangement is coded in the following manner:

| | |
|---|---|
| Column 10 | 0 Pores lacking |
| | 1 Without arrangement |
| | 2 Radially and obliquely arranged |
| | 3 Radially arranged only |
| | 4 Obliquely arranged only |
| | 5 Ulmiform |
| | 6 Tangential |
| | 7 Dendritic |
| | 8 Festooned |
| | 9 Arc-porous |

Each card, when completely punched represents a compact assemblage of information on the anatomical, physical, chemical, taxonomic, and geographical characteristics of one species. The completed cards may be maintained in a single large unit or may be assembled into smaller units according to specific anatomical characters, country of origin or other classifications.

"The system makes it possible to determine for each individual case what is the quickest way of arriving at an identification since the order of the features used in identification is not fixed as is the case of present day keys. In use, the particular features of the sample are observed and the code number for the feature recorded. The cards are then sorted according to the coded notations until the card corresponding to the species of the sample is segregated.

"Though the proposed key is being developed for the use of the IBM punched card and sorting system, it will not be confined exclusively to that system. In fact the coded data can be assembled for use as a printed key without the use of punched cards at all, or the data can be adapted to the use of other types of punched cards such as the marginally perforated cards. Another feature of the scheme is that the key can be made to include as many species as desired by simply adding or removing the coded data for that species. This makes it particularly applicable for use by pulp and paper manufacturers whose interest may be in only from 150 to 200 species at most and often many less.

"Since the proposed system will be universal in character, it is essential that the organization and coded characteristics be universally accepted. The problems involved in the development of a universal code were discussed at the meeting of Inter-

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Right here at home, in the heart of the Fox River Valley, you'll also find the paper industry. All of these neighborhood mills know, from long experience, that *Appleton Wires are Good Wires!*

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national Association of Wood Anatomists held in conjunction with the Seventh International Botanical Congress at Stockholm, Sweden in July."

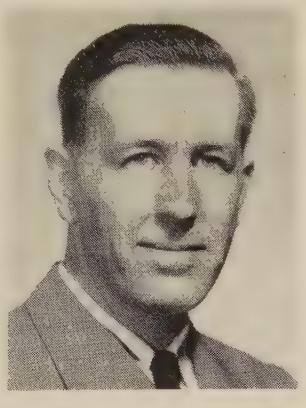
## *Pulp Testing Committee*

The sessions of the Pulp Testing Committee at Rochester were devoted to the following major subjects:

Project No. 140 "Dirt in Pulp." Because of the importance of identifying the nature of the dirt this project was considered, in part, jointly with the Microscopy Committee.
Project No. 333. Revision of T 215 m-45 "Forming Handsheets for Physical Testing of Pulp."
Project No. 335. Fiber Classification (Jointly with the Microscopy Committee).

Consideration was given to such subjects as "Specific External Surface of Pulp and the "Zero-span Test as Applied to Pulp."

*E. R. Schafer, Chairman, Fibrous Material Testing Committee*



*L. V. Forman, Chairman, Pulp Testing Committee*

At this and previous meetings of the Committee some time was spent on the general subject of interpreting the results of pulp testing. The Chairman pointed out the need for correcting for density as well as for weight in many cases. Examples were cited in which check tests sometimes lacked agreement because of slight (and sometimes unavoidable) variations in wet pressing, blotters, etc. If corrected for density as well as for weight, the discrepancies disappeared and good checks were obtained. The Chairman also raised the question of plotting the various strength properties against the logarithm of time instead of against time and urged the Committee to investigate this matter in their own laboratories and build up some experience with it. In some cases it shows great promise for reducing the number of tests required for adequate results.

The personnel of the Pulp Testing Committee is as follows:

L. V. Forman, Institute of Paper Chemistry, Appleton, Wis., *Chairman.*
H. K. Benson, University of Washington, Seattle, Wash.
H. W. Bialkowsky, Weyerhaeuser Timber Co., Longview, Wash.
C. E. Brandon, Howard Paper Mills Co., Dayton, Ohio.
H. Y. Charbonnier, Union Bag & Paper Corp., Savannah, Ga.
W. F. Holzer, Crown Zellerbach Corp., Camas, Wash.
F. C. Schroeder, Northwest Paper Co., Cloquet, Minn.
G. H. Sheets, Mead Corp., Chillicothe, Ohio.
R. C. Sproull, Southern Research Institute, Birmingham, Ala.
R. I. Thieme, Soundview Pulp Co., Everett, Wash.

## *Nonfibrous Materials Testing Committee*

The Nonfibrous Materials Testing Committee is nearly as old as the Technical Association itself and has produced the large number of methods in the 600-series that appear in the TAPPI Standards.

The present chairman is James P. Casey of the New York State College of Forestry, Syracuse, N. Y. Assisting him are:

C. G. Albert, Edgar Brothers Co., McIntyre, Ga.
D. D. Cameron, Hercules Powder Co., Wilmington, Del.
L. C. Jenness, University of Maine, Orono, Me.
C. C. Kesler, Penick & Ford Ltd., Cedar Rapids, Iowa.
S. I. Kukolich, Lee Paper Co., Vicksburg, Mich.
L. L. Larson, Detroit Sulphite Pulp & Paper Co., Detroit, Mich.
L. H. Silvernail, Dow Chemical Co., Midland, Mich.
M. R. Wilkins, Kalamazoo Paper Co., Kalamazoo, Mich.

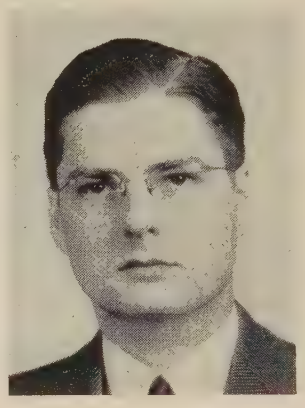
Because of the wide diversification of testing methods handled by this committee the greater part of the work is carried on by subcommittees dealing with specific subjects.

C. C. Kesler is chairman of the subcommittee for the development of testing procedures suitable for beater, surface sizing, and coating starches. The members of this subcommittee, in addition to Dr. Kesler are:

F. E. Culp, Consolidated Water Power & Paper Co., Wisconsin Rapids, Wis.
F. H. Frost, S. D. Warren Co., Cumberland Mills, Me.
J. E. Getty, West Virginia Pulp and Paper Co., Luke, Md.
L. O. Gill, A. E. Staley Mfg. Co., Decatur, Ill.
S. I. Kukolich, Lee Paper Co., Vicksburg, Mich.

Attempts are being made to organize a subcommittee for the testing of enzymes. In view of the relation between starches and enzymes the work of this subcommittee will be closely correlated with the Starch Subcommittee.

A project on the testing of clays is in active progress under the direction of C. G. Albert of Edgar Brothers Co. This project covers the development of testing methods for both



*James P. Casey, Chairman, Nonfibrous Materials Testing Committee*

*Milton F. Fillius, Chairman, Chemical Methods Committee*

filler and coating clays, separate from the present TAPPI Standard T 615 m. The members of this subcommittee in addition to Dr. Albert are:

R. B. Blakeslee, Imperial Paper & Color Corp., Glens Falls, N. Y.
C. W. Clark, St. Regis Paper Co., Deferiet, N. Y.
H. F. Kohne, West Virginia Pulp & Paper Co., Luke, Md.
M. R. Wilkins, Kalamazoo Paper Co., Kalamazoo, Mich.

D. D. Cameron of the Hercules Powder Co., is chairman of the subcommittee on rosin size testing.

L. H. Silvernail of the Dow Chemical Co., Midland, Mich., is chairman of a subcommittee to review the present standard methods of analysis of coal, gasoline, analytical reagents, and indicators. These methods have been critized as being out of date. Any member of TAPPI who may have suggestions for the improvement of these methods is urged to write to Dr. Silvernail.

The chairman of the aforementioned subcommittees would appreciate hearing from members of the Association who feel that they can help in dealing with the projects mentioned.

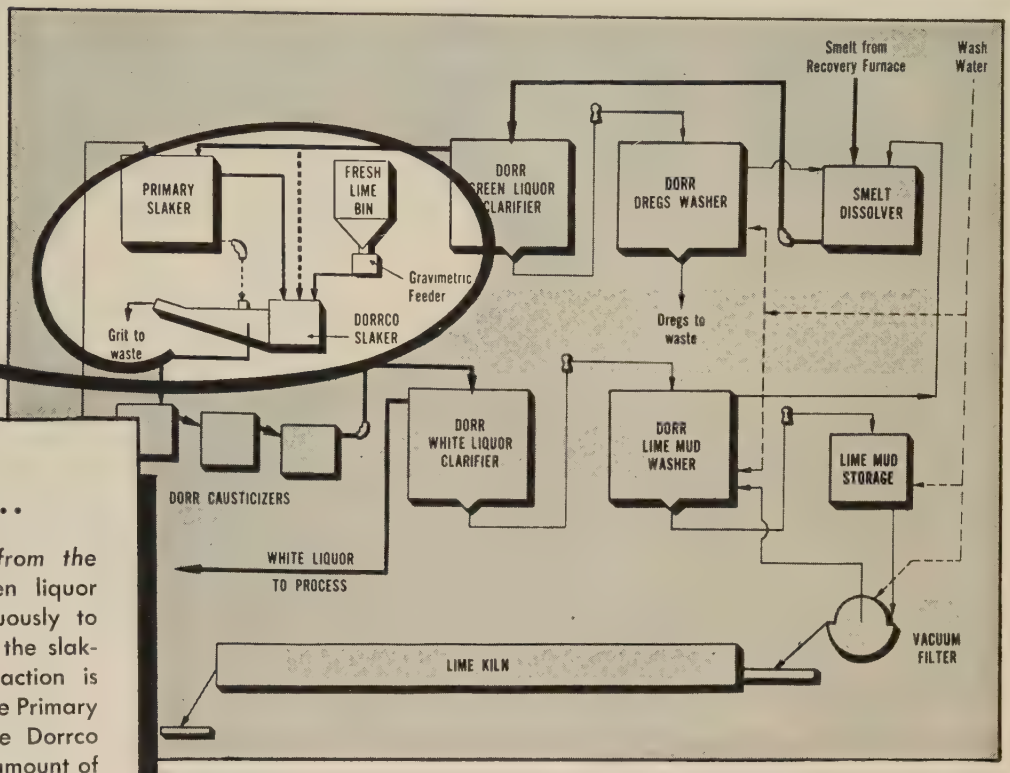
## *Paper Testing Committee*

The program of the Paper Testing Committee at the Test-

# what's NEW in recausticizing plant practice?

# 2 stage lime slaking!

The slaking station of the Dorr Continuous Recausticizing System . . . standard of the industry . . . has been redesigned to provide an even higher degree of operating efficiency.




## here's the flowsheet...

Reburned lime, *direct from the kiln,* and clarified green liquor are now added continuously to a Primary Slaker where the slaking and recausticizing action is started. Overflow from the Primary is fed by gravity to the Dorrco Slaker and a measured amount of makeup lime is added. Slaking is completed in the Dorrco, which produces a clean milk of lime and a washed, separated grit. The remainder of the flowsheet is the standard Dorr System.

## here are its advantages...

- Troublesome handling of hot lime is reduced to a minimum . . . need for reburned lime bin is eliminated.
- Accurate weighing of makeup lime results in "end point" control with no over or under liming.
- Uniform white liquor strength is maintained regardless of fluctuations in kiln discharge.

*If you are interested in alkaline pulping processes, write for a new bulletin #3301 describing the Dorr Continuous Recausticizing System in detail.*

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ing Conference was devoted to a review of the following existing methods: T 409 (Machine Direction of Paper); T 411 (Thickness and Density of Paper); T 426 (Bulking Thickness of Paper); T 431 (Ink Absorption of Blotting Paper; T 432 (Water Absorption of Biblious Papers, and Paperboards); T 445 (Specks and Spots in Paper); and (Pin Holes in Paper).

*L. E. Simerl, Chairman, Packaging Materials Testing Committee*

*A. H. Croup, Chairman, Optical Properties Committee*

A. K. Warner, Skinner & Sherman, Inc., Boston, Mass., is Chairman of the Paper Testing Committee. Associated with him are:

G. J. Brabender, Marathon Corp., Rothschild, Wis.
J. d'A. Clark, Consulting Engineer, Longview, Wash.
R. M. K. Cobb, Lowe Paper Co., Ridgefield, N. J.
P. W. Codwise, Beaver Wood Fibre Co., Thorold, Ont.
L. V. Forman, Institute of Paper Chemistry, Appleton, Wis.
M. S. Kantrowitz, Government Printing Office, Washington, D. C.
B. W. Scribner, National Bureau of Standards, Washington, D. C.
L. E. Simerl, Marathon Corp., Menasha, Wis.
H. A. Smith, Mead Corp., Chillicothe, Ohio.
P. F. Wehmer, Electrical Testing Laboratories, New York, N. Y.
B. L. Wehmhoff, West Virginia Pulp & Paper Co., Chevy Chase, Md.
R. H. Wiles, International Paper Co., Glens Falls, N. Y.

## *Chemical Methods Committee*

The Chemical Methods Committee held two sessions at the Rochester Testing Conference.

On Thursday, September 14, Dr. Geoffrey Broughton, Head of the Department of Pulp and Paper Engineering, Lowell Textile Institute, Lowell, Mass., led a discussion of some of the basic principles and practical points of the determination of the moisture content of pulp, paper, and analytical residues such as alpha-cellulose, etc., encountered in gravimetric procedures. These methods include T 209, T 412, and T 410.

Dr. A. S. O'Brien of the Eastman Kodak Co., led a discussion of the changes in composition of the liquid in the distilling flask resulting from the step-wise addition of hydrochloric acid during the distillation step on the pentosan determination (T 223).

Dr. O'Brien also led a discussion of the need for a more rapid procedure for determining the nitrogen content of paper (T 418).

On Friday, September 15, Prof. F. W. O'Neil, New York State College of Forestry, Syracuse, N. Y., led a discussion of TAPPI methods T 214 (Permanganate Number of Pulp), T 219 (Bleach Requirements of Pulp), and T 202 (Chlorine Consumption of Pulp).

A general discussion followed of the complications introduced in the analysis of papers containing wet-strength resins, for alpha-cellulose, copper number, etc.

Milton F. Fillius of the Eastman Kodak Co., Rochester, N. Y., is Chairman of the Chemical Methods Committee. Associated with him are:

S. I. Aronovsky, Northern Regional Research Laboratory, Peoria, Ill.
Geoffrey Broughton, Lowell Textile Institute, Lowell, Mass.
B. L. Browning, Institute of Paper Chemistry, Appleton, Wis.
C. P. Donofrio, New York State College of Forestry, Syracuse, N. Y.
R. S. Hatch, Consultant, Monterey, Calif.
W. F. Holzer, Crown Zellerbach Corp., Camas, Wash.
M. S. Kantrowitz, Government Printing Office, Washington, D. C.
E. F. Kurth, Oregon State College, Corvallis, Ore.
A. F. Martin, Virginia Cellulose Div., Hercules Powder Co., Wilmington, Del.
A. S. O'Brien, Eastman Kodak Co., Rochester, N. Y.
T. A. Pascoe, Nekoosa-Edwards Paper Co., Port Edwards, Wis.
E. P. Samsel
J. C. Tongren, Hammermill Paper Co., Erie, Pa.
A. K. Warner, Skinner & Sherman, Inc., Boston, Mass.
B. F. Wehmer, Electrical Testing Laboratories, New York, N. Y.
Peter Van Wyck, Hercules Powder Co., Wilmington, Del.

In addition to the main committee there are subcommittees on Alpha, Beta, and Gamma-Cellulose, Disperse Viscosity, Wood, pH of Paper Extracts, Reducible Sulphur, and Moisture in Pulp.

## *Packaging Materials Testing Committee*

At the Rochester meeting the Packaging Materials Testing Committee devoted its attention to its major current projects: 1. Project 277. Water Vapor at Zero F.; 2. Project 328. Flavor and Odor Transfer; 3. Project 330. Testing Pressure Sensitive Tapes; and 4. Project 357. Water Permeability of Completed Packages.

L. E. Simerl, Marathon Corp., Menasha, Wis., is Chairman of the Packaging Materials Testing Committee. Associated with him are:

W. H. Aiken, Goodyear Tire & Rubber Co., Akron, Ohio.
P. S. Barnhart, Westfield River Paper Co., Russell, Mass.
L. F. Borchardt, General Mills, Inc., Minneapolis, Minn.
A. B. Brackett, General Foods, Inc., New York, N. Y.
A. J. Cameron, Canadian Industries, Ltd., Montreal, P. Q.
L. C. Cartwright, Foster D. Snell, Inc., New York, N. Y.
J. d'A. Clark, Consulting Engineer, Longview, Wash.
R. deS. Couch, General Foods, Inc., Hoboken, N. J.
T. E. Dobbins, American Can Co., Maywood, Ill.
H. S. Gardner, Fibreboard Products, Inc., Antioch, Calif.
C. W. Hoffman, Riegel Paper Corp., New York, N. Y.
C. E. Hrubesky, Forest Products Laboratory, Madison, Wis.
A. H. Landrock, Mass. Inst. of Technology, Cambridge, Mass.
C. C. Lavers, Maple Leaf Milling Co., Toronto, Ont.
F. D. Long, Container Corp. of America, Chicago, Ill.
J. C. Plankinton, Western Waxed Paper Co., San Lorenzo, Calif.
G. R. Sears, Institute of Paper Chemistry, Appleton, Wis.
C. A. Southwick, Jr., Consultant, Hope, N. J.

## *Optical Properties Committee*

The Optical Properties Committee devoted its session at Rochester to the final draft of the proposed tentative standard for Gloss of Paper and the report of the results of the use of the National Bureau of Standards fading papers for calibrating Fadometers and the possibility of recommending these for general use in the industry.

A. H. Croup, Hammermill Paper Co., Erie, Pa., is Chairman of the Optical Properties Committee. Assisting him are:

H. H. Bell, New York & Pennsylvania Co., Lock Haven, Pa.
F. B. Lincoln, Hollingsworth & Whitney, Waterville, Me.
J. L. Parsons, Hollingsworth & Whitney, Waterville, Me.
B. W. Scribner, National Bureau of Standards, Washington, D. C.
P. F. Wehmer, Electrical Testing Laboratories, New York, N. Y.
J. d'A. Clark, Longview, Wash.

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. . . And Experience tells under all conditions as well. Out of knowledge and experience come intelligent solutions for today's problems—and those on tomorrow's horizon.

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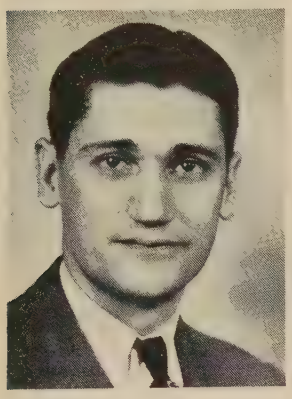
ADVISORY SUBCOMMITTEE:

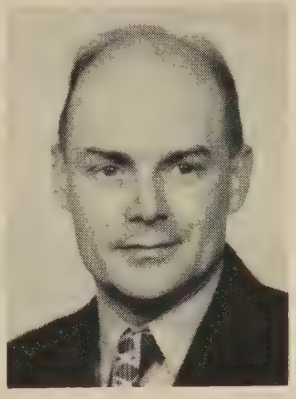
A. C. Hardy, Mass. Inst. of Technology, Cambridge, Mass.
J. A. van den Akker, Institute of Paper Chemistry, Appleton, Wis.
R. S. Hunter, Gardner Laboratories, Washington, D. C.

## *Microscopy Committee*

C. E. Brandon, Aetna Paper Co. Div., Howard Paper



*C. E. Brandon, Chairman, Microscopy Committee*



*A. M. Heald, Chairman, Joint Committee on Petroleum Wax*

Mills, Dayton, Ohio, succeeded Thomas Fyfe of the Eastman Kodak Co., as Chairman of the Microscopy Committee.

Associated with Mr. Brandon are:

C. P. Donofrio, New York State College of Forestry, Syracuse, N. Y.
Thomas Fyfe, Eastman Kodak Co., Rochester, N. Y.
H. C. Koch, Aetna Paper Co., Dayton, Ohio.
F. L. Simons, Crane & Co., Dalton, Mass.
R. H. Simmons, Government Printing Office, Washington, D. C.
N. F. Wilson, Alton Box Board Co., E. Alton, Ill.
William Landes, Paper and Pulp Testing Laboratories, New York, N. Y.
Leon Senike, Crown Zellerbach Paper Corp., Camas, Wash.

At the Rochester meeting consideration was given to TAPPI Standard T 213 m-43 (Project 140) Dirt in Pulp, T 401 m-42 (Project 335) Fiber Composition of Paper, and the differentiation of alpha-treated softwood sulphite and highly bleached sulphite with the C-stain, the revision of T 8 (Species Identification of Wood and Wood Fibers), the use of the microscope in analyzing for mineral fillers in papers, tests for elemental sulphur in paper, and the measurement of fiber length by the optical method of the Eastman Kodak Co., and the routine method of the Alton Box Board laboratory.

## *Joint Committee on Petroleum Wax*

To coordinate the work of the American Society for Testing Materials and TAPPI on problems dealing with wax evaluation a TAPPI-ASTM Joint Committee on Petroleum Wax was established at the TAPPI annual meeting in February, 1950 and met at the TAPPI Testing Division Conference at Rochester.

In response to a letter 30 oil companies and 30 paper companies and general interests accepted invitations to participate and offer laboratory facilities. The joint committee will report to the Wax Testing Committee of TAPPI on laboratory facilities. The joint committee will report to the Wax Testing Committee of TAPPI and as Technical Committee M to ASTM-D2.

A. M. Heald, Marathon Corp., Menasha, Wis., is chairman of the joint committee. R. B. Killingsworth, Socony-Vacuum Oil Co., Brooklyn, N. Y., is vice-chairman, and A. P. Anderson, Shell Oil Co., New York, N. Y. is secretary.

The following constitute the Advisory Section:

T. A. Howells, Institute of Paper Chemistry, Appleton, Wis
G. C. Borden, Jr., Riegel Paper Corp., Milford, N. J.
J. C. Plankinton, Western Waxed Paper Co., San Lorenzo, Calif.
E. W. Gardner, California Research Corp., San Francisco. Calif.
J. W. Padgett, Moore & Munger Co., New York, N. Y.

The scope of the committee has been set to cover methods of test, nomenclature, and specifications for petroleum wax.

The following sections have been established:

I. Strength Tests (1. Tensile Strength, 2. Modulus of Rupture) J. W. Padgett, Moore & Munger Co., New York, N. Y., *Chairman.*
II. Flow Tests (1. Flexibility, 2. Hardness, 3. Volume Expansion, and 4. Viscosity) Kenneth G. Coutlee, Bell Telephone Laboratories, Murray Hill, N. J., *Chairman.*
III. Stability Tests (1. Oxidation Stability and 2. Light Stability). G. P. Hinde, Jr., Shell Oil Co., Houston, Texas, *Chairman.*
IV. Sensory Tests (1. R. I., 2. Color-solid wax, 3. Odor, 4. Taste, and 5. Transparency). G. D. Fronmuller, Scott Paper Co., Chester, Pa., *Chairman.*
V-A Composition (Melting Point and Oil Content) J. B. Rather, Jr., Socony-Vacuum Oil Co., Brooklyn, N. Y., *Chairman.*
V-B Composition (1. Melting Point Distribution). F. H. MacLaren, Standard Oil Co. (Indiana), Whiting, Ind., *Chairman.*
VI. Blocking. M. W. Kane, Kalamazoo Vegetable Parchment Co., Kalamazoo, Mich., *Chairman.*
VII. Sealing and Laminating. George C. Borden, Riegel Paper Corp., Milford, N. J., *Chairman.*
VIII. Scuff-Gloss. G. P. Mueller, Marathon Corp., Menasha, Wis., *Acting Chairman*

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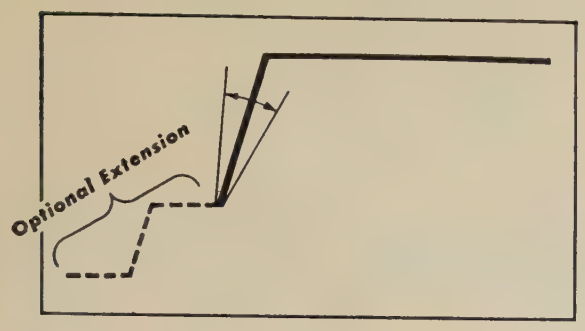
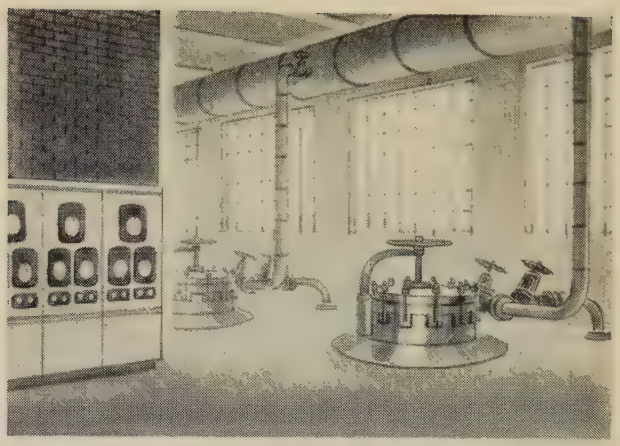
CANTON, MASS.



# Digester Control WITHOUT CAMS

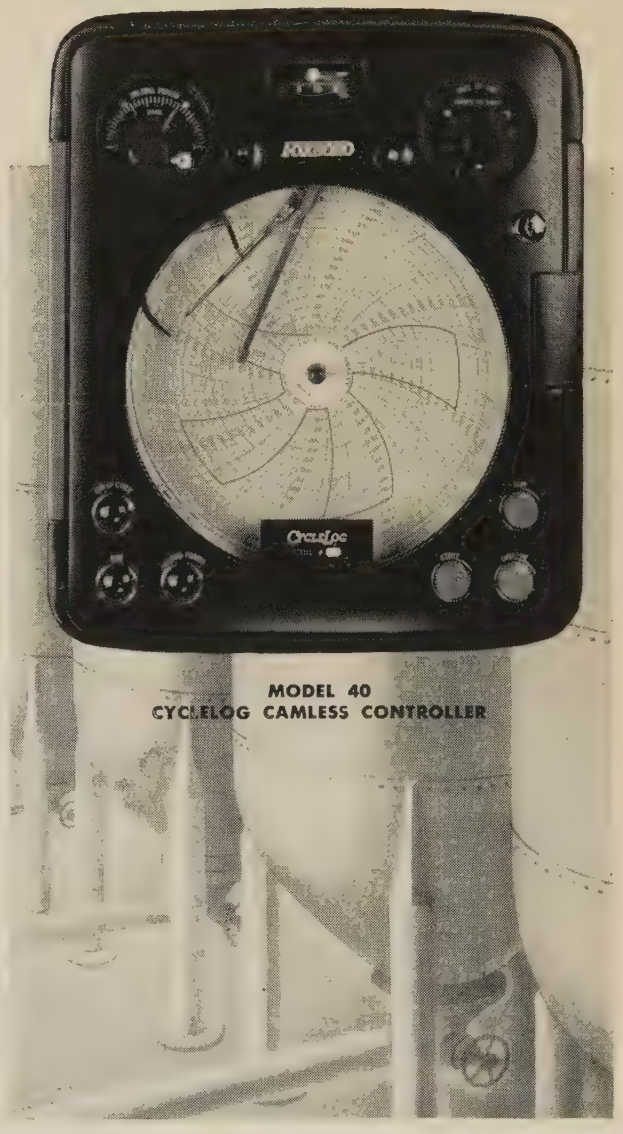
## *Easiest, fastest adjustment for changes in operating conditions*

At the simple turn of a knob, you can now shift easily and quickly from one complete cooking schedule to another to compensate for changes in liquor or acid strength, moisture content of the chips, type of pulp desired. *No cams to cut or change.* And established temperature or pressure schedules can be repeated at will, merely by pushing a button!

Other advantages offered by the Model 40 CycleLog Controller include: (1) Controlled rate of rise with stepless dial-selection between 0.5 and 7.0°F. per min. (or between 0.5 and 5.5 psi per min.); (2) holding temperature (or pressure) and time period easily set by convenient knobs; (3) continuous chart record; (4) case-contained push buttons and signal lights simplify installation and reduce panel space.

**IN ADDITION** — an optional feature of the Model 40 CycleLog Controller establishes a constant base temperature starting point for every cook, (with adjustable holding time) eliminating the effects of variable charging temperatures — a "natural" for sulphite cooking.

Find out more about this revolutionary development for pulp mill operation. Write for Bulletin 438, and talk it over with your Foxboro Field Engineer. **The Foxboro Company, 78 Neponset Ave., Foxboro, Mass., U. S. A.**

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**AUTOMATIC DIGESTER CONTROL**

# LOCAL SECTION ACTIVITIES

***Reports of Meetings, Personnel and Events***

## *Maine-New Hampshire*

The fall meeting of the Maine-New Hampshire Section will be held at Colby College, Waterville, Me., Oct. 13–14, 1950.

This meeting will be held in connection with the opening of the new Keyes Science Bldg. Room reservations should be made at the Elmwood Hotel, Waterville, Me.

## *Lake Erie*

The first fall metting of the Lake Erie Papermakers' and Converters' Association will be held at the Hickory Grille, Cleveland, Ohio.

## *Delaware Valley*

The Executive Committee of the Delaware Valley Section met at the Engineers' Club on Tuesday evening, August 8, to discuss the schedule of meeting dates, the type of programs, and other pertinent business of the coming year.

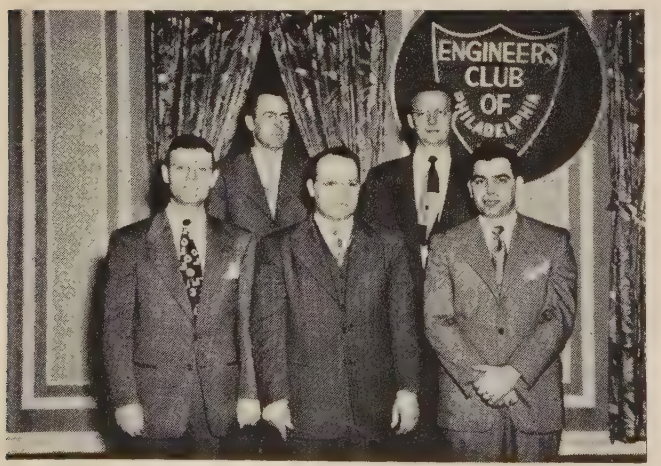
The first meeting of the coming year will be Thursday, Sept. 28, 1950, and will be a visit to Triangle Publishers, Inc., North Broad and Callowhill Streets, Philadelphia, followed by a dinner and meeting at the Engineers' Club in the evening. The guest speaker of the evening will be Harrison F. Dunning, Manager of Paper Mills, Scott Paper Company, whose topic will be "Human Relations in Industry."

The complete schedule of meeting dates for the 1950–1951 season is as follows:

Thursday, Sept. 28, 1950 at the Engineers' Club
Thursday, Oct. 26, 1950 at the Engineers' Club
Thursday, Nov. 30, 1950 at the Engineers' Club
Thursday, Jan. 25, 1950 at the Engineers' Club
Thursday, March 22, 1950 at the Engineers' Club
Thursday, April 26, 1950 at the Engineers' Club
Thursday, May 24, 1950 at the Engineers' Club

The Executive Committee meeting was attended by R. G. Macdonald, Ralph W. Kumler, D.V.S. representative in the National TAPPI Executive Committee; Dr. A. S. Erspamer, P. H. Glatfelter Company, *chairman;* Dr. Arthur J. Haug, Scott Paper Company, *first vice-chairman;* Dr. Harold C. Brill, E. I. du Pont de Nemours, *second vice-chairman;* Frank J. Lovegren, W. C., Hamilton & Sons, *treasurer;* E. R. Padavic, Container Corporation of America, *secretary;* and John Macadam, National Vulcanized Fibre Company, and John P. Weidner, Container Corporation of America of the *Executive Committee* for the Delaware Valley Section.

E. R. Padavic




***Front row: Arthur J. Haug, August S. Erspamer, and Emil R. Padanic; rear row: Harold C. Brill and Frank J. Lovegren***

## *Review of Local Section Meetings in 1949–1950*

The following is a record of the meetings held by the TAPPI Local Sections during the past year. The season of meetings usually begins in September and ends in June. In the past years this record has been published in the TAPPI Year Book.

## *Pacific*

The Pacific Section was organized at Seattle, Wash., in June, 1929. The annual meeting is usually held in May.

*Sept. 11–15, 1949:* (Multnomah Hotel, Portland, Oregon) National Fall Meeting.

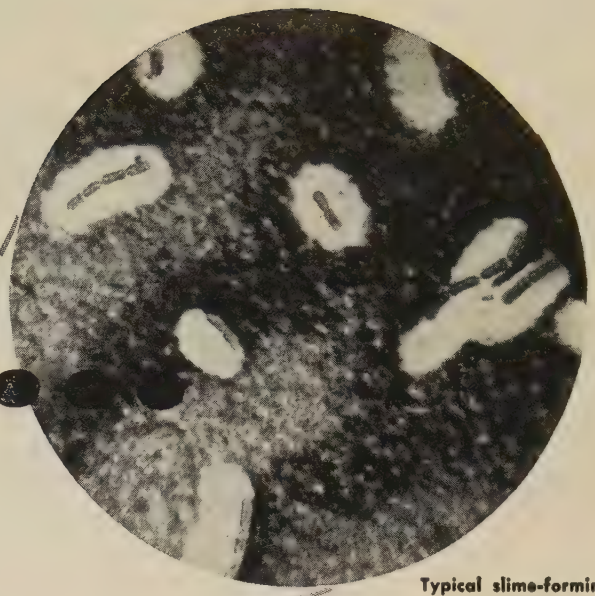
*Oct. 25, 1949:* (Tacoma, Wash.) Subject, "Instrumentation." 1. "Electronics in the Paper Industry," Fred Thompson, General Electric Co., Seattle, Wash.; 2. "pH Control on Paper Machines," Howard C. Hall, Crown Zellerbach Corp., Camas, Wash.; 3. "Basis-Weight Control on Paper Machines," Wallace Sawyer, Portland, Ore.; 4. "Consistency Control Using the Photoelectric Cell," H. T. Peterson, Weyerhaeuser Timber Co., Pulp Division, Longview, Wash.; 5. "Sulphur Level Control in Rotary Sulphur Burners," Forrest Williams, Crown Zellerbach Corp., Camas, Wash.; 6. "Measurement and Control of Chlorine," Brian L. Sherea, Pennsylvania Salt Mfg. Co. of Washington, Tacoma, Washington. Dinner Speaker: Howard W. Morgan, Weyerhaeuser Timber Co., Pulp Division, Tacoma, Wash.

*Dec. 6, 1949:* (Longview, Wash.) Joint Meeting with Pacific Coast Division, Superintendents Association. 1. "Fabricating Quality and Performance into Corrugated Shipping Containers," A. O. Parson, Longview Fibre Co., Longview, Wash.; 2. "Quality Control Through Consumer Acceptance Inspection," James B. Brown and R. L. Cochran, Western Waxed Paper Co., North Portland, Ore.; 3. "Technical Control of Converting Operations," J. A. Butterick, Crown Zellerbach Corp., Camas, Wash.; 4. "Management Problems in Converting Operations," B. F. Warren, Crown Zellerbach Corp., Camas, Wash.; 5. "Materials Handling in Paper Converting," R. P. Wollenberg, Longview Fibre Co., Longview, Wash.; 6. "Preconditioned Paper," H. R. Russell, Everett Pulp & Paper Co., Everett, Wash.; 7. "Paperboard Conversion," R. C. McKee, Institute of Paper Chemistry, Appleton, Wis.

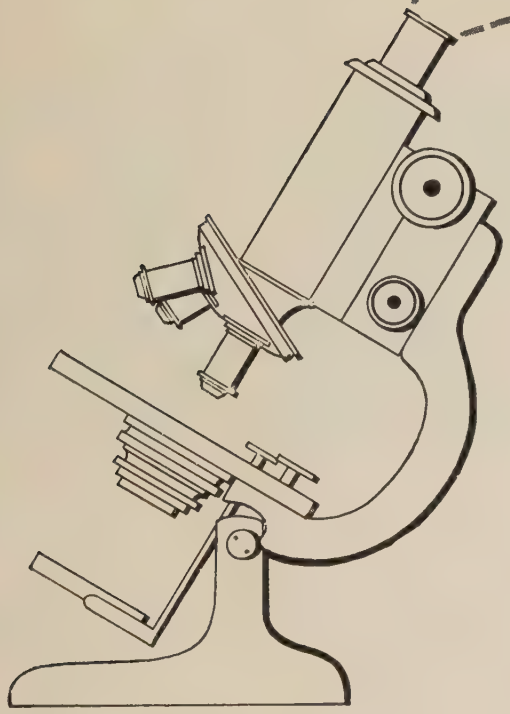
*Feb. 7, 1950:* (Everett, Wash.) Annual Engineering Meeting. 1. "Neutral Grounding of Industrial Power Systems," by C. D. Ries, Industry Specialist, General Electric Co., Seattle, Wash.; 2. "Engineering Materials and the Factors Influencing Their Uses," by L. M. Johnson, Resident Engineer, Soundview Pulp Co., Everett, Wash.; 3. "Some Recent Developments in the Burning of Hogged Fuel," by Otto de Lorenzi, Publicity Director, Combustion Engineering Co., New York, N. Y.; 4. "Development Engineering in the Pulp and Paper Industry" by P. R. Sandwell, Consulting Engineer, Beecher and Sandwell, Vancouver, B. C. Dinner Speaker, Dean Harold E. Wessman, College of Engineering, University of Washington, Seattle, Wash.

*April 7, 1950:* (Camas, Wash.) The Annual Shibley Award Contest. 1. "Determination of Total Solids in Ammonia Base Sulphite Waste Liquor by Conductometric Measurements," by Berry W. Bailey, Soundview Pulp Co., Everett, Wash.; 2. "Product Segregation in a Paper Mill," by William F. Farley, Crown Zellerbach Corp., Camas, Wash.; 3. "Salinity of Saltwater Borne Wood," by John T. Firestone, Weyerhaeuser Timber Co., Pulp Division, Everett, Wash.; 4. "Furnish Calculations

# kill these pests...



Typical slime-forming organisms



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Quality conscious paper mill superintendents know from experience that chlorination, engineered to their stock or white water requirements by Wallace & Tiernan, effectively eliminates such slime-induced troubles as pin holes, slime spots, and poor sheet formation.

Such results—which have saved up to 400 dollars per day in many mills—are possible because chlorination kills the organisms that *cause* slime. It may be used alone on the fresh water supply, or together with chloramines or other corrective chemicals on the white water, for effective slime control in such key spots as the showers, screens, deckers, and at many other points.

Wallace & Tiernan Chlorinators are particularly effective in slime control work because they are especially designed from over 35 years' experience to give low cost, efficient performance.

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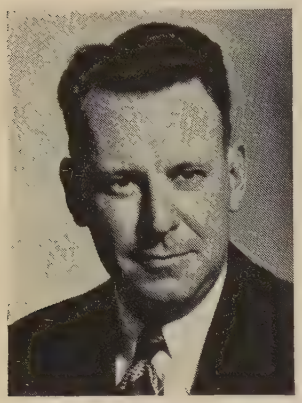
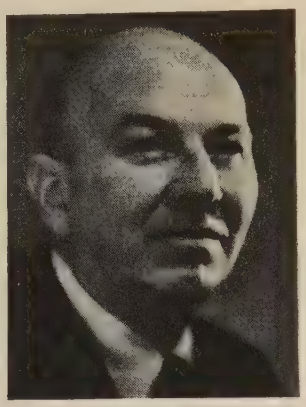
I-34

on Beater Fed Machines," by William S. Milne, Publishers' Paper Co., Oregon City, Ore.; 5. "Nomographs and Their Application to Continuous Kraft Bleaching," by Emerick J. Dobo, Crown Zellerbach Corp., Camas, Wash.; 6. "Design of Packed Absorption Towers" by Dr. F. B. West, Asst. Professor of Chemical Engineering, University of Washington. Dinner Speaker, H. A. "Gob" Des Marais, "Impressions on a Trip to Japan."



***Robert I. Thieme, Chairman, 1950–1951, Pacific Section***



***Robert M. True, Secretary-Treasurer, Pacific Section***

*May 11, 12, 13, 1950:* (New Washington Hotel, Seattle, Wash.) Tri-Association Meeting with Pacific Coast Division, Superintendents Association and Pacific Coast Branch, Technical Section Canadian Pulp and Paper Association. The annual business meeting for the election of officers was also held. "Camas Paper School," by W. C. Jacoby, Crown Zellerbach Corp., Camas Wash.; "Preconditioned Paper," by H. R. Russell, Everett Pulp and Paper Co., Everett, Wash.; "Duties and Responsibilities in the Pulp and Paper Mill," by E. P. Barthelemy, Crown Zellerbach Corp., Camas, Wash.; "An Analysis of Some Sulphite Waste Liquor Processing Schemes," by J. L. McCarthy, Dept. of Chemistry and Chemical Engineering, University of Washington, Seattle, Wash.; "The Magnesium Oxide Sulphite Waste Liquor Recovery Process," by Svarre Hazelquist, Weyerhaeuser Timber Co., Longview, Wash. and Charles Rogers, Babcock & Wilcox Co.; "The Performance of Cowan Screens on Western Groundwoods," by A. R. Ferguson, Pacific Mills Ltd., Ocean Falls, B. C.; "Heat Transfer from Hot Moist Air in a Spray Tower," by D. L. Stewart, Powell River Co. Ltd., Powell River, B. C.; "Current Research in the Division of Cellulose Chemistry at McGill University," by C. B. Purvis, Professor Industrial and Cellulose Chemistry, McGill University.

## *Lake States*

*Oct. 11, 1949:* "Dyestuffs in the Paper Industry," by Otto Kress, Institute of Paper Chemistry, Appleton, Wis.

*November 8, 1949:* Afternoon visit at the Mosinee Paper Mills Co. and at the new research laboratory of the Marathon Corp. at Rothschild, Wis. In the evening at Wausau "The Utilization of Waste Sulphite Liquor" by J. R. Salvesen, Marathon Corp., Rothschild, Wis. and "A Summary of Stream Pollution Problems from the Point of View of a Kraft Mill," by T. A. Pascoe, Nekoosa-Edwards Paper Co., Port Edwards, Wis.

*Dec. 13, 1949:* "The Elimination of the Human Element in Determining Printing Quality," by Dr. R. A. Diehm, Ward Paper Co., Merrill, Wis.

*Jan. 10, 1950:* "Observations of a European Junket," by N. L. Malcove, Northern Paper Mills, Green Bay, Wis.

*Feb. 14, 1950:* "Waxes in Protective Packaging," by Harold Corbin, Socony-Vacuum Oil Co., Brooklyn, N. Y.

*March 14, 1950:* "Paper and Packaging Requirements of the Quartermaster Corps," by Albert V. Grundy, Chief, Container Research and Development Division, Quartermaster Food and Container Institute for the Armed Forces, Chicago, and Ray C. Martin, Consultant, Chemical and Plastics Section, Research and Development Branch, Military Planning Division, Office of the Quartermaster General, Washington.

*April 11, 1950:* Afternoon session at the Forest Products Laboratory, Madison, Wis. "Opportunities for Utilization of Lake States Woods for Coarse Fiber Products," by G. K. Chidester, P. K. Baird, C. E. Hrubesky, J. N. McGovern, and S. L. Schwartz, Forest Products Laboratory. Evening session at Loraine Hotel, Madison. "Stream Pollution Control Activities in Wisconsin," by T. F. Wisniewsky, Director, Committee on Water Polution in Wisconsin.

*May 9, 1950:* "Fourdrinier Wires, by John P. Gerhauser, Appleton Wire Works, Appleton, Wis. and "The Microbiological Degradation of Woolen Felts," by B. F. Shema, Institute of Paper Chemistry, Appleton, Wis.

## *Delaware Valley*

The Delaware Valley Section was organized at Philadelphia in June, 1931. Meetings are held monthly at the Engineer's Club in Philadelphia unless otherwise indicated.

*Oct. 7, 1949:* Tour of P. H. Glatfelter Company mill at Spring Grove, Pa., during afternoon. Dinner and meeting held at Yorktowne Hotel, York, Pa. "Recent Developments in Papermaking Machinery," by Charles Adams assisted by G. A. Peterson, both of Rice Barton Corp. Equipment shown on large photographs was the basis of the talk.

*Oct. 27, 1949:* "Rainbows to Order," a motion picture, "Putting Rainbows on Paper," a talk and demonstration by George Welp, IPI Division, Interchemical Corp., New York, N. Y.

*Nov. 30, 1949:* "Modern Quality Control," a motion picture and talk by Simon Collier, Johns-Manville Corp., Manville, N. J.

*Jan. 26, 1950:* "Sizing" Panel Discussion—Arthur J. Haug, Scott Paper Company, Moderator. Panel Members: Thage Dahlgren, Pioneer Salt Works, H. F. Heller, Hercules Powder Company, G. D. Lord, American Cyanamid Co., and William Wilson, Monsanto Chemical Company.

*March 23, 1950:* "Drying of Paper," by A. E. Montgomery, J. O. Ross Engineering Corp., Chicago, Ill.

*April 7, 1950:* "Pulp Testing," by K. P. Geohegan, Aetna Paper Company Division, The Howard Paper Mills, Inc., Dayton, Ohio.

*May 25, 1950:* "Paper Mill Maintenance" Panel Discussion—Moderator: Harry C. Merritt, Downingtown Manufacturing Company, Downingtown, Pa. Panel Members: C. M. Connor, W. C. Hamilton and Sons, Miquon, Pa.; George E. Ellis, Jr.,

***Henry C. Crandall, Chairman, 1950–1951, Lake States Section***

***August S. Erspamer, Chairman, 1950–1951, Delaware Valley Section***

Scott Paper Company, Chester, Pa.; C. F. King, Westinghouse Electric Corporation, Philadelphia, Pa.; N. B. Rohrbaugh, P. H. Glatfelter Company, Spring Grove, Pa.; and Karl R. Wolf, Scott Paper Company, Chester, Pa.

## *Kalamazoo Valley*

The Kalamazoo Valley Section was organized at Kalamazoo, Mich. May 4, 1931. Its meetings are held on the first Thursday of each month at the Columbia Hotel unless otherwise specified.

*Oct. 6, 1949:* "White Water and Water Management," by C. F. Hauck of Hall Laboratories, Pittsburgh, Pa.

*Nov. 3, 1949:* "Jordan Plug Pressure-Control System," by Bruno E. Prevost of the Emerson Manufacturing Co., Lawrence, Mass.

*Dec. 1, 1949:* "Shade and Quality Control in the Dyeing of Paper," by H. A. Lips E. I. du Pont de Nemours & Co., Wilmington, Del.

*Jan. 12, 1950:* "Paper Makers Get-together" Joint meeting with American Pulp and Paper Mill Superintendents Association,

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Choose "SOLKA" for extraordinary endurance and flexibility. This pulp is the foundation of really tough ledger papers. Performance has earned "SOLKA" first position in the sturdy-paper field.

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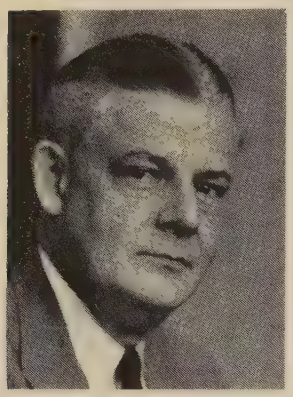
Michigan Division, R. A. Hayward, Kalamazoo Vegetable Parchment Co., Kalamazoo, Mich. Toastmaster.

*Feb. 2, 1950:* "Biological and Pest Control in the Paper Industry," by R. W. Kingerly E. I. du Pont de Nemours & Co., Wilmington, Del.

*March 2, 1950:* "Recent Developments in Pulping and their Effects on the Converter," by H. W. Bialkowsky, Weyerhaeuser Lumber Company, Longview, Wash.



***G. A. Day, Chairman, 1950–1951, Maine-New Hampshire Section***

***R. J. Proctor, Chairman, 1950–1951, New England Section***

*April 6, 1950:* "Graphic Arts Day" (1) "Gravures Place in the Graphic Arts Industry," Joe Martin, Champlain Co.; (2) "Developments in the Printing Ink Industry," by Milton Zucker International Printing Ink Co., New York, N. Y.; (3) "Xerography and Ferographic Printing," by Chester F. Carlson, Haloid Company; (4) "Printers Paper Troubles," by Robert H. Simmons, U. S. Government Printing Office, Washington, D. C.

*May 4, 1950:* "Moisture Measurement and Control," by Norman R. Stilwell, Foxboro Co., Foxboro, Mass.

*June 1, 1950:* Golf Outing-Recreational Session with election of officers.

## *Maine-New Hampshire*

The Maine-New Hampshire Section was organized at Orono, Me., on Oct. 25, 1940 and received its charter on Oct. 26, 1945.

*Oct. 21–22, 1949:* (Lafayette Hotel, Portland, Maine). "Trend of Plastics in the Pulp and Paper Industry," by W. H. Aiken, Assistant Manager, Chemical Division, Goodyear Tire and Rubber Company; "Use of Natural and Modified Starches in the Beater," by O. R. Steffens, Penick and Ford, Ltd.; "Manufacturing of Plastic by the Beater Addition Process," by Francis H. Snyder, President of Snyder Chemical Company; "Influence of Surface Properties of Fibers on Paper Making," by Edward F. Thode, Assistant Professor of Chemical Engineering, University of Maine, Orono, Maine; "Application of Radio-Activity Techniques to Paper Making," by A. P. Schrieber, Tracer Laboratories, Inc., Boston, Massachusetts. A panel discussion followed on "Starches and other Beater Additives."

*June 23–24, 1950:* (The Wentworth-by-the-Sea, Portsmouth, New Hampshire). "Some Theoretical Aspects of Fiber Motions in Paper Making," by S. G. Mason, Pulp and Paper Research Institute of Canada; "Some Observations on Paper Making Fibers," by W. V. Torrey, S. D. Warren Company, and also by R. H. Doughty, Fitchburg Paper Company; "The Properties of Pulp as Related to Chemical Composition," by I. B. Douglass, University of Maine, Orono, Maine; "Effect of Fiber Characteristics on Paper and Paper Making Properties, by W. Gallay, The E. B. Eddy Company, Hull, Quebec. Representatives from the Sutherland Refining Corp., Rice Barton Corp., John W. Bolton and Sons, Downingtown Manufacturing Company, E. D. Jones and Sons, Inc., Sprout, Waldron and Company, Inc., Shartle Brothers Machine Company, participated in an informal panel discussion on the practical aspects of stock refining.

## *New England*

The New England Section was organized at Holyoke, Mass. on December 9, 1932. The following meetings were held during the past year at the places indicated:

*Sept. 30, 1949* (Red Lion Inn, Stockbridge, Mass.): The general theme of this meeting was "Tubsizing." R. A. Gale of Pillsbury Mills, Inc. spoke on "Enzyme Conversion"; "Equipment" was discussed by P. B. Holden, Stowe Woodward Co., Newton Upper Falls, Mass.; "Starches" was the topic of J. Newton, Clinton Foods, Inc., Clinton, Iowa; "Practical Mill Problems" was discussed by Robert Pattison of Cellulose Fibres, Inc., Holyoke, Mass.; "Starches" by O. Steffins, Penick & Ford, Ltd., New York, N. Y.

*Nov. 18, 1949* (Toto's Smiths Ferry, Mass.): "Is Peace Possible" by Harry G. Specht, Vice-President and General Manager of Eastwood-Nealley Corp; Peter S. Sinclair, President of the Sinclair Co., gave a resume of his recent European trip.

*Jan. 20, 1950* (Hotel Northampton, Northampton, Mass.): R. H. Mosher of Holyoke Card & Paper Co. acted as moderator for a panel composed of the following: "The Theory of Adhesives" by Dr. Frank C. Campins of Polymer Industries, Inc., New York, N. Y.; "Laminating Machinery for Paper and Paper Board" by Lawrence W. Egan of Frank W. Egan & Co., Bound Brook, N. J.; "Information Necessary for Technical Service on Adhesives" by J. J. Austin of Austin Industries; "Specialty Paper-to-Paper Laminants" by Mr. Bearman of Paisley Products, Inc., New York, N. Y.

*March 24, 1950* (Hotel Sheraton, Worcester, Mass.): The theme of this meeting was "The Paper Industry and Technical Education" and the program was in charge of Geoffrey Broughton, head of the new Paper Dept. at Lowell Textile Institute, Lowell, Mass. The problem was briefly outlined by John J. Desmond, Jr., Commissioner of Education for Massachusetts; President Kenneth R. Fox of Lowell Textile Institute and Prof. Geoffrey Broughton.

*June 23–24, 1950* (The Wentworth By-the-Sea, Portsmouth, New Hampshire): This was a joint meeting of the Maine-New Hampshire Section and the New England Section and the "Theoretical Aspects of Stock Preparation" were featured in the first technical session.

## *Ohio*

The Ohio Section was organized on Nov. 30, 1934 at Middletown, Ohio. Meetings were held during the past year at the Hotel Manchester, Middletown, Ohio and the McCall Corp., Dayton, Ohio.

*Oct. 13, 1949:* "Opportunities Through Research," by Allen Abrams, Marathon Corp., Rothschild, Wis.

*Nov. 8, 1949:* This meeting was held at the McCall Corp., Dayton, Ohio. After dinner at the company cafeteria the group was escorted on a tour through the McCall plant.

*Dec. 8, 1949:* "The Legal Phases of Water Pollution Control in Ohio," by F. H. Waring, Ohio Department of Health, Columbus, Ohio.

*Jan. 10, 1950:* "Chemical By-Products of the Wood Pulp Industry," by Dr. Harry F. Lewis, Institute of Paper Chemistry, Appleton, Wis.

*Feb. 9, 1950:* "The Engineers Selection of the Paper Machine Drive," by R. A. Packard, Holyoke Machine Company, Holyoke, Mass. Joint meeting with the Miami Valley Superintendents Division.

*March 14, 1950:* Panel, "Pulp Testing Procedures." Moderator: C. E. Brandon, Aetna Paper Company, Dayton, Ohio. Members of the panel: Howard Laymon, Mead Corporation, Chillicothe, Ohio; E. F. Parmenter, Champion Paper and Fibre Company, Hamilton, Ohio and D. J. Goodman, Sorg Paper Company, Middletown, Ohio.

*April 13, 1950:* "The Curlator," by James F. Coghill, The Curlator Corp., Rochester, N. Y.

*May 11, 1950:* Annual meeting and election of officers. Speaker, R. J. Anderson, Battelle Memorial Institute, Columbus, Ohio.

## *Empire State*

The Empire State Section began holding meetings in 1935, and received its charter on April 2, 1938. In 1943, the Section was organized with four regional Groups, and, in 1948, a fifth, Metropolitan group was added.

During the past year, Group meetings were held at Glens Falls, New York City, Niagara Falls, and Watertown. The Central Group at Syracuse was inactive.

The Annual Meeting was held at the Thousand Islands Club, Alexandria Bay, N. Y. on June 25–27, 1950.

EASTERN GROUP (S. Glens Falls, 3rd Thursday of Month)

*Oct. 20, 1949:* "The General Application of Transite Pipe for

# THE MIDWEST-FULTON MACHINE CO.

Engineers in Principal Papermaking Areas

DAYTON 2, OHIO

## HI-SPEED PULPERS

Will *completely slush* up to 60 tons of virgin pulp or broke per day, depending on size of unit, and do it on input load of only 60 H.P. Will out-perform any other pulping agent on basis of complete make-down —no small pieces, no shiners, no fish eyes. Thoroughness of its work will lighten load on beaters and prolong their life. In some mills have actually replaced beaters. Reasonably priced. Fairly prompt deliveries.

## HOLLANDER BEATERS

Over the past 25 years hundreds of Midwest hi-speed Hollanders have been built and mills still interested in standard beaters, or obliged to replace or repair existing equipment, may count on prompt service.

## MODERN AUTOMATIC PRECISION BEATERS

Very fast. Will replace four or five standard beaters and do their work far better. Controls can be set to duplicate exactly any previous furnish. Because input load works largely on the stock rather than just to circulate it, the savings in power are alone sufficient to amortize entire investment reasonably soon. In light of work done, way it is done, and economies effected, very reasonably priced.

## FULTON DRYER DRAINAGE SYSTEMS

In neighborhood of 75% of all paper machines now have Fulton drainage equipment on their dryer sections. Here's why. Drying capacity increased up to 30%. Moisture content closely controlled. Graduated temperature curve on wet end dryers, starting low to avoid cockling, curling, case hardening, breaks in sheet. Lower average drying temperatures and return of condensate to boilers at maximum temperatures effects steam saving up to 20%—several thousands of dollars in any mill—alone sufficient to pay for system in couple of years. If not Fulton-equipped, join the 75%.

## SIGHT-FLOW CONDENSATE INDICATORS

Double-check condition of your dryers. Install Ball sight-flow indicators on return headers, make certain of ample condensate flow and check the temperature. Avoid sins of faulty drying—cockling, curling, case hardening, excessive broke losses. Pyrex glass ball "window" positively will not cloud over but stay clear at all times. Non-corrosive equipment and good for many years. Inexpensive. Easy to install. Nothing to wear out.

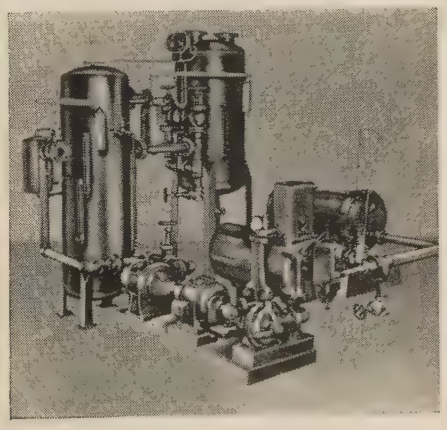
## AUTO-FLEX SYPHONS

Overcome faults of ordinary syphons. Don't discount that statement and smile because it is a literal fact and can be proved—is being proved every day in the year. This equipment positively stays in position and insures entire removal of water and air from dryers. Will fit any dryer. Easy to install. No adjusting when being installed or afterwards. Syphon easy on steam joint. Try a few and see for yourself.

## PROPELLER AGITATION

Properly designed chests and effective agitation of the stock in them is just as important as pulping, beating, jordaning, pumping, or any other mill operation. Midwest can engineer chests to meet the mill layout and agitation requirement; also build the agitator. Single- or multiple-blade agitators for horizontal or vertical operation as required. Consult us on agitation.

Midwest Hi-Speed Pulper



Fulton Dryer Drainage

Midwest Automatic Precision Beater

the Pulp & Paper Industry," by S. A. Tompkins, Johns-Manville Corp., New York, N. Y.

*Nov. 17, 1949:* "Choosing the Correct Mechanical Power Transmission Method," by William A. Staniar, Consultant for J. E. Rhoads & Sons, Wilmington, Del.

*Dec. 15, 1949:* "Dryer Bearing Lubrication with Particular Reference to Circulating Systems Encountered on Modern Paper Machines," by Walter S. Miller, Gulf Oil Company, Pittsburgh, Pa.

***Donald J. Goodman, Chairman, 1950–1951, Ohio Section***

***Albert K. Roach, Chairman, 1950–1951, Chicago Section***

*Jan. 19, 1950:* "Waxes for Protective Packaging," by John C. Dean, Socony Vacuum Oil Company, New York, N. Y.

*Feb. 16, 1950:* "Wood By-Products," by Dr. E. F. Wesp, Electrochemicals Div. of the du Pont Co., Niagara Falls, N. Y.

*March 16, 1950:* "Pulp & Paper Mill Instrumentation," by Harold Sholl, The Brown Instrument Co., Philadelphia, Pa.

*April 20, 1950:* "Woolen Felts in the Pulp & Paper Industry," by Lawrence Woodside, Albany Felt Company, Albany, N. Y.

*May 18, 1950:* "Isotopes in Industry and the Use of the Beta Ray Thickness Gauge," by Walter Mikelson, General Electric Company, Schenectady, N. Y.

METROPOLITAN GROUP (Fraunces Tavern, 2nd Tuesday of Month)

*Sept. 13, 1949:* "Impressions of Conditions in Europe," by Harry Specht, Eastwood-Nealley Corp., Belleville, N. J.

*Oct. 11, 1949:* "Collective Bargaining," by George Brooks, International Brotherhood, Pulp, Sulphite & Paper Workers, A. F. of L., Fort Edward, N. Y.

*Nov. 14, 1949:* "Trends in the Pulp & Paper Industry," by John Cornell, Paper Mill News, New York, N. Y.

*Jan. 10, 1950:* "Uses of Radio Isotopes in Industry," by W. C. Nusbaum, Tracerlab Inc., Boston, Mass.

*March 14, 1950:* "Recent Trends in Wood Pulp with Emphasis on the Competition from Paper and Non-Paper Users," by James L. Ritchie, Executive Director of the U. S. Pulp Producers Association, New York, N. Y.

*April 11, 1950:* "Putting the Rainbow to Work," by George Welp, International Printing Ink Co., New York, N. Y.

WESTERN GROUP (Prospect House on 2nd Wednesday of Month)

*Oct. 12, 1949:* "Pulpstones," by W. W. Barrett, Carborundum Company, Niagara Falls, N. Y.

*Nov. 9, 1949:* "Trade Unions in American Industry," by J. P. Burke, President, International Brotherhood of Pulp and Sulphite Workers, Fort Edward, N. Y.

*Dec. 14, 1949:* "The Story of the Curlator Development," by J. T. Coghill, Curlator Corp., Rochester, N. Y.

*Feb. 8, 1950:* Panel Program Discussing Felt Problems, by Howard Brown, Lockport Felt Co., Lockport, N. Y.; Lawrence Woodside, Albany Felt Co., Albany, N. Y.; Irving Peters, F. C. Huyck & Sons, Rensselaer, N. Y.; Fred Parkinson, H. Waterbury & Sons, Oriskiny, N. Y.

*March 8, 1950:* "Discussion of Operations in Producing an Issue of Time Magazine," by B. O. Chapman, Time Inc., New York, N. Y.

*April 12, 1950:* "Conversion Products from Paper Material," by E. A. Russell, Spaulding Fiber Company, Tonawanda, N. Y.

*May 10, 1950:* "A Conception of Slime and Its Control in the Paper Industry", by R. S. Shumard, Monsanto Chemical Co., St. Louis, Mo.; "Slime Control," by W. D. Stitt, Buckman Laboratories, Memphis, Tenn.; "The Dilemma of Choosing the Proper Slime Control Agent," by H. J. Wilkoyte, du Pont Co., Wilmington, Del.; "Planning and Adhering to a Slime Control, Program," by I. A. Clausen, National Aluminate Company, Hamburg, N. Y.; "Chlorination for Slime Control," by R. B. Martin, Wallace & Tiernan Co., Newark, N. J.

NORTHERN GROUP (Hotel Woodruff on 2nd Thurs. of Month)

*Oct. 13, 1949:* "The Practical Aspects of Statistical Control," by R. T. Trefla, Hercules Powder Company, Wilmington, Del.

*Nov. 10, 1949:* "The Use of Radioisotopes in the Paper Industry," by W. C. Nusbaum, Tracerlab Inc., Boston, Mass.

*Dec. 8, 1949:* "Trends in Engineering Education," by J. H. Davis, President, Clarkson College of Technology, Potsdam, N. Y.

*Jan. 12, 1950:* "The Chemistry of Starch and its Application to the Paper Industry," by Jerry Strasser, Stein, Hall & Co., Inc., New York, N. Y.

*Feb. 9, 1950:* "Itinerary of a Traveling Engineer of England's and Europe's Paper Industry," by J. Walter Couture, Dilts Machine Works, Fulton, N. Y.

*April 13, 1950:* "What the Paper Industry Means to New York State," by Henry J. Perry, *Paper Trade Journal*, New York, N. Y.

*May 11, 1950:* Ladies Night.

ANNUAL MEETING (The Thousand Islands Club, Alexandria Bay, N. Y.) June 25–27, 1950: "Resistant Alloys as Applied to Flow Control in the Pulp & Paper Industry," by W. H. Heilig, Powell Valve Co.; "The Curlator," by J. T. Coghill, The Curlator Company, Rochester, N. Y.; "The Practical Art of Color Matching Paper," by Dr. E. I. Stearns and F. O. Sundstrom, Calco Div., American Cyanamid Company, Bound Brook, N. J.; "Petroleum Products in Paper Making," by J. F. Butterworth and W. A. Beeman, Socony Vacuum Oil Co., New York, N. Y.; "Resin Bonding in Paper," by C. G. Landes, American Cyanamid Company, Stamford, Conn.; "Review of Silicate of Soda in Paper Mill Use," by Robert MacGonagle, Philadelphia Quartz Company, Philadelphia, Pa.; "Application 'OCO' to Water Systems in Paper Mill Recovery," Sandy Hill Brass & Iron Works, Hudson Falls, N. Y.

## *Lake Erie*

The Lake Erie Papermaker's and Converter's Association was organized at Cleveland, Ohio on Oct. 7, 1949. Meetings are held on the third Friday of every month at the Hickory Grill, 929 Chester Ave., Cleveland, Ohio.

*Oct. 7, 1949:* "Paper and Paperboard Finishes," P. C. Plehn, Consolidated Paper Co.; E. E. Thomas, Appleton Machine Co.; and K. B. Latimer, Time, Inc.

*Nov. 18, 1949:* "How Sizing Affects You," by W. O. Manor, Consolidated Paper Co.; "Use and Theory of Sizing," by P. F. Neumann, Hercules Powder Co.; and "Tests for Sizing of Paper and Paperboard," by R. L. Leaf, Jr., Ohio Boxboard Co.

*Dec. 9, 1949:* "Electronics in Paper Industries," by R. C. Berger, General Electric Co., and "Color Control in Paper Conversion," by W. C. Granville, Container Corp. of America.

*Jan. 20, 1950:* "What Poor Safety Tools Cost You," by H. G. Hays, Greater Cleveland Safety Council and Ohio State Safety Council; and "The Future Relationship Between the Petroleum and Paper Industries," by H. P. Ferguson and M. S. Obenauff, Standard Oil Company of Ohio.

*Feb. 17, 1950:* "Labor Management Relationships within the Industry, Past, Present, and Future," by S. A. Stephens, International Brotherhood of Pulp, Sulphite, and Paper Mill Workers.

*March 17, 1950:* "What's New in Adhesives," by M. E. Stern, Federal Adhesives Co.; E. S. Gantt, Corn Products Refining Co.; and R. L. Pett, National Starch Products.

*April 21, 1950:* "Odors in Relation to Paper Products and Packaging," by L. B. Sjöström, Arthur D. Little, Inc.

*May 19, 1950:* "Printing Inks," by J. Steinbrunner, International Printing Ink Co.

*July 21, 1950:* Summer Party at Brookside Country Club, Barberton, Ohio, with plant visits to Chase Bag Co., and Ohio Boxboard Co.

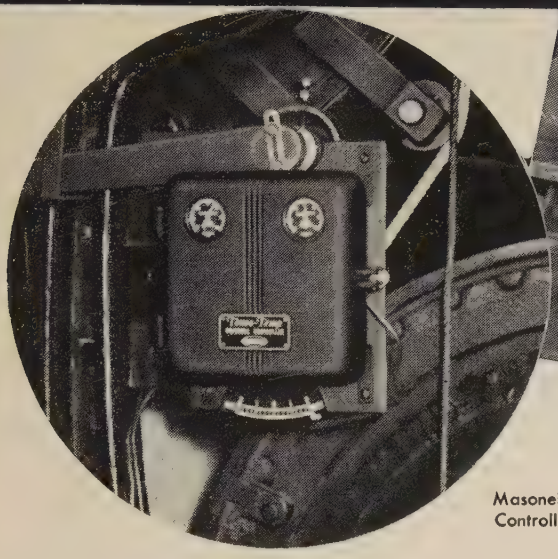
## *Chicago*

The Chicago Section was organized under the name of the Chicago Professional Paper Group, Chicago, Ill., in October, 1943. Three years later the Group became affiliated as a local Section of TAPPI. All meetings are held on the evening of the third Monday of each month at the Chicago Bar Association.

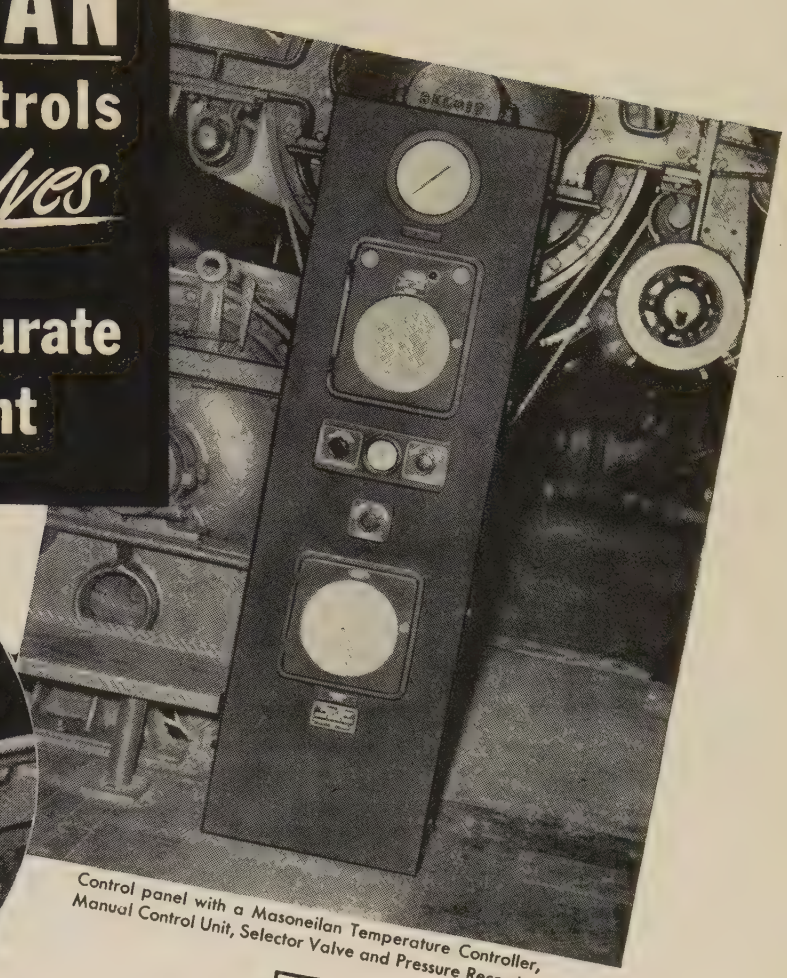
*Sept. 19, 1949:* "The Advantages of Plastic Printing Plates as Compared with Metal Plates," by E. M. Paulsen, Plastic Printing Plates, Inc., Chicago, Ill.

# MASONEILAN

## Tenso-Temp Controls *Pay for Themselves* by Maintaining Accurate Moisture Content



Masoneilan Moisture Controller



Control panel with a Masoneilan Temperature Controller, Manual Control Unit, Selector Valve and Pressure Recorder

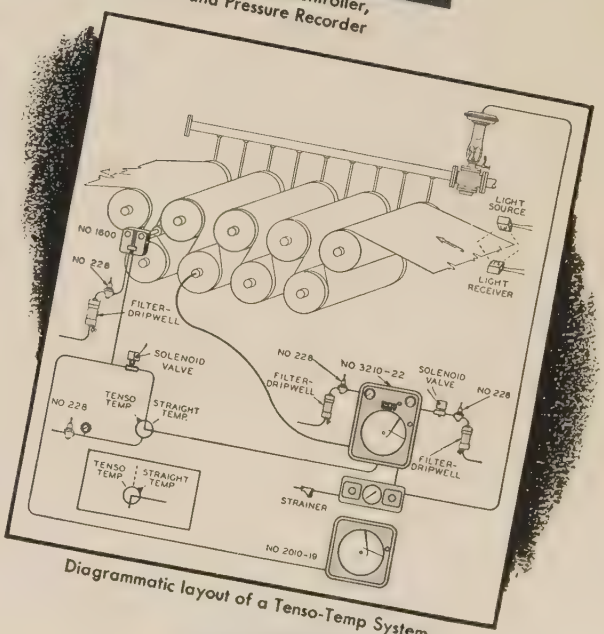
In paper mill after paper mill, Masoneilan Tenso-Temp Controls are paying for themselves by reducing waste, providing more uniform quality and minimizing rejects. That's why you find Tenso-Temp specified and used in new installations and in modernization programs. Consider these additional advantages that make Tenso-Temp worth investigating for your mill.

**Tenso-Temp is accurate** because moisture contact measurement is averaged for the full width of the sheet. Response is instantaneous . . . variations in weight across the sheet do not produce false indication and inaccurate control.

**Tenso-Temp is sensitive** to the slightest variations in moisture content . . . precisely adjustable to maintain the desired moisture.

**Tenso-Temp is economical** because original cost is moderate and maintenance and operating costs are at a minimum.

**Tenso-Temp is adaptable** to any type of paper from condenser to board.




Diagrammatic layout of a Tenso-Temp System

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*Oct. 17, 1949:* "The Role of Radioisotopes in the Paper Industry," by L. W. Mead, Tracerlab, Inc., Chicago, Ill.

*Nov. 21, 1949:* "Press Make-Ready of Printing Plates," by Burt Rike, Technical Executive, Lakeshore Electrotype Co., Chicago, Ill.

*Dec. 13, 1949:* Annual Suppliers Night Christmas Party.

*Jan. 16, 1950:* "An Introduction to Research," by Dr. H. A. Leedy, Director, Armour Research Foundation, Illinois Institute of Technology, Chicago, Ill.

*Feb. 20, 1950:* "Machines for Manufacture of Set-Up Boxes," by Douglas T. Neale, President of High Production Machine Co., Philadelphia, Pa.

*March 20, 1950:* "Paperboard for Folding Cartons," by Dr. W. C. Wilson, Vice-President, Pyroxylin Products, Inc., Chicago, Ill.

*April 17, 1950:* "Printing Inks," by J. Watson, Mgr. of Technical Service Dept., J. M. Huber Corp., New York, N. Y.; "Gravure & Aniline Inks," by R. H. Scott, Assistant Plant Mgr., Sinclair & Valentine Co., Chicago, Ill.; "Offset Inks," by Charles Beutner, Director of Offset Sales, Sigmund-Ullman Co., Chicago, Ill.

*May 15, 1950:* "Vegetable Adhesives for Packaging Machines and Future Adhesive Requirements for Speed Packaging," by Roger Shoals, Manager, Adhesive Dept., Stein-Hall & Co., Inc.; "Animal Glues," by Samuel Shuller, Technical Director, Paisley Prod., Inc.; "Synthetic Resins and Latest Developments in the Resin Field," by R. L. Pett, Resin Technical Service, National Adhesives Div., National Starch Prod., Inc., all of Chicago, Ill.

## *Electric Power Distribution Systems**

The subject of fundamental design of electric power distribution systems for industrial plants has been very thoroughly covered in recent years in numerous technical reports, papers, and engineering journal articles. Distribution systems must be designed to satisfy a great variety of conditions, ranging from those of the large area high-load plants down to those of the small area light-load factories.

In general, when planning a distribution system for any plant the following basic conditions must be considered first; (a) type of industry, (b) amount of load to be distributed, (c) character of load such as necessity for uninterrupted service, and (d) area covered by plant. With this information at hand, a study can then be made to decide the following: (a) scheme of distribution, (b) location of distributing centers, (c) voltage to be used, and (d) method of distribution, i.e., whether underground or overhead. Each of the above factors must be weighed carefully before the type of distribution system best adapted to a particular plant can be determined.

The discussion which follows will describe the distribution systems of a small paperboard plant.

This plant consisted of a group of closely connected buildings occupying an area approximately 400 by 600 feet. The plant was equipped for making coated paperboard with usual machinery required for this purpose including beaters, pulpers, refiners, pumps, calenders, etc. There were two steam engine driven paper machines. The power plant consisted of one 1500 kw., 480-volt turbine generator, which with bus and feeder panels was located in a building near the center of the plant. All distribution was at 480 volts. The existing power generating and distribution system was outgrown due to the rapidly increasing demand for paperboard and an increase in facilities was necessary. The changes considered included the replacement of old with new processes, the addition of new drives, and the motorizing of the two engine-driven paper machines.

The total demand of the mill was approximately 2000 kw., of which half was generated and the other half purchased from the local utility company, the amount of load generated being determined by the demand for low-pressure steam exhausted from the turbine. Studies determined that the proposed process changes would increase the demand to about 3000 kw., all of which it was proposed to generate in the plant.

There were a total of 170 motors ranging from 200 hp. down, about 20% of which were of 100 hp. or over rating. Due to the gradual addition of new equipment during the past years, feeders had been added one or two at a time until there were 18 leaving the central plant switchboard. Many of these were originally intended for one machine only, but as time passed, they had been tapped for additional equipment until they were badly overloaded. All feeders were controlled by oil or air circuit breakers of low interrupting capacity which would have to be replaced with any increase in generating capacity.

A careful study of the mill steam and electrical loads resulted in the decision to install two new 2000 kw. turbine generators, the existing 1500 kw. unit to be removed because of its age and very inefficient performance. The next step was to determine whether to continue generating at 480 volts or change to a higher voltage. Estimates were made for two conditions.

(1) New generator rated 2300 volts with distribution at 2300 volts to load centers in the heavy load areas and distribution at 480 volts to light load areas.
(2) All generation and distribution at 480 volts.

In the 2300-volt scheme, a new 2300-volt metal-clad switchgroup would be connected to the existing 480-volt bus through a 2400/480 volt tie bank. Three new 2300-volt feeders would be run to load centers in the heaviest load areas, and the remaining lightly loaded sections of the mill fed by 480-volt feeders direct from the existing 480-volt board. Each of the load centers would consist of a 2300-volt bus from which the larger motors would be fed direct through circuit breakers or fused starters, and a step-down transformer supplying a 480-volt metal-clad switchgroup from which the smaller motors would be served. All new motors of 100 hp. or over would be rated 2300 volts, and since one phase of the plant expansion proposed the addition of ten drives in that range, there appeared to be an advantage for the higher voltage. Three 2300-volt and seven 480-volt feeders were required for this scheme, or ten total as compared with the 18 then operating.

In the case of all generation and distribution at 480 volts, new switchgear would be installed for both generators and all feeders, and the old feeder boards removed from service. Feeders would be run to load centers in the mill much as in the first scheme except that they would all be at 480 volts. Plant motors would be fed through breakers in the new load centers. This scheme required a total of 13 feeders.

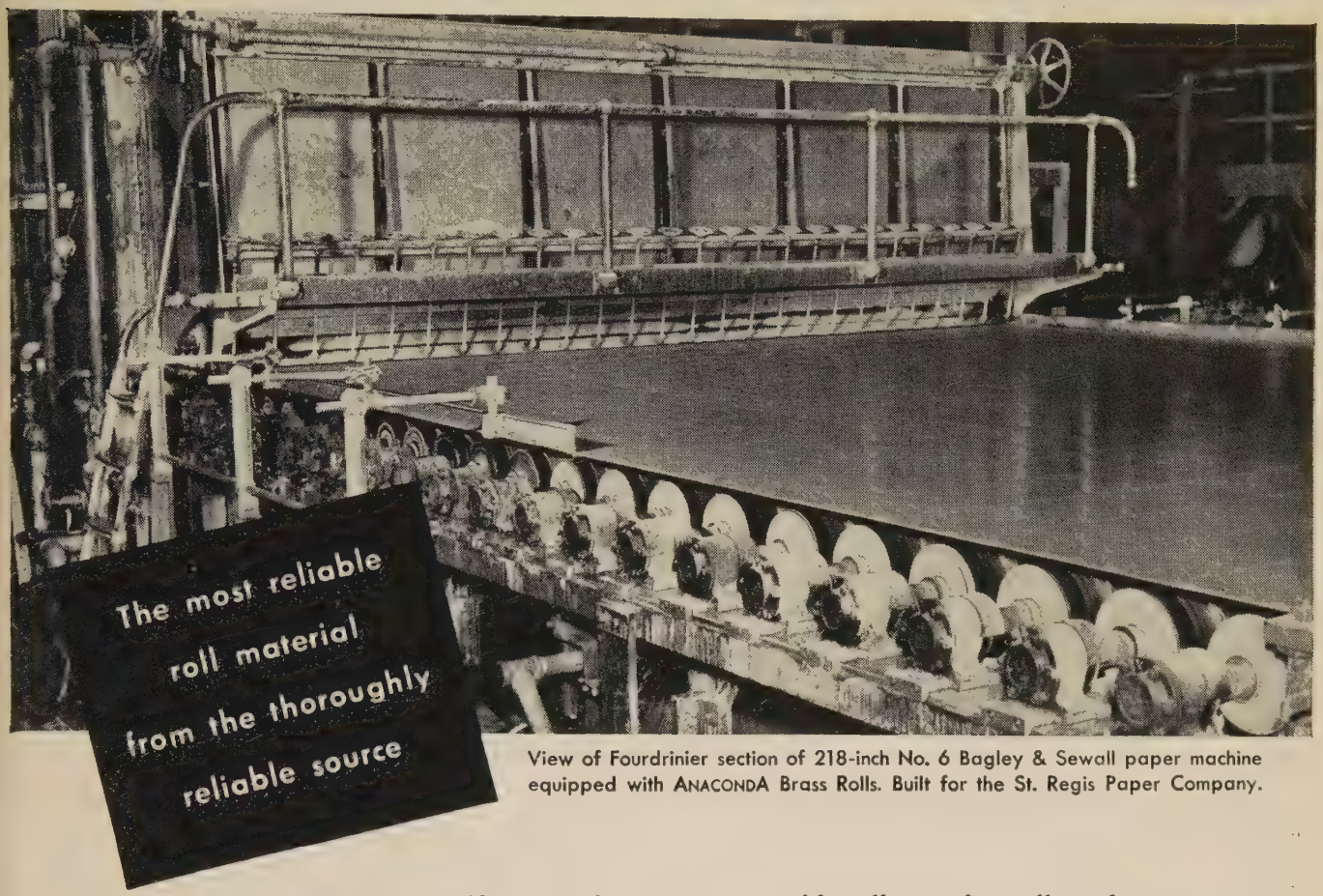
The next higher voltage of 4150 was also considered, but for this particular plant, there would have been no saving in switchgear and little in feeder costs, and as the cost of new motors would be slightly higher there was no advantage in adopting the higher voltage.

A comparison of the installed costs of the two schemes, including new generator and feeder switchgear, new feeders and load centers, showed a saving of approximately 20% in favor of the 480-volt generation scheme and this scheme was therefore adopted. Feeder losses could have been reduced by using the higher voltage, but the heavy load feeders were all very short, not exceeding 100 feet, and the losses therefore not an important factor. This was particularly true since power was being generated by non-condensing turbines, the exhaust from which was used for mill processes.

The use of bus duct was considered for the main feeders to the mill areas, but ruled out due to the wet atmosphere and the many problems of interference with machinery and piping in the areas in which it would have been most applicable. Feeders consisted of three single-conductor cables in iron conduit, two or more sets of conductors in parallel being used were necessary.

* Part of paper presented at the 12th Annual Midwest Power Conference, Sherman Hotel, Chicago, Ill., April 5–7, 1950, by S. L. Chapin, Sargent & Lundy, Engineers, Chicago, Ill.

# Specify ANACONDA Brass for your paper machine rolls




View of Fourdrinier section of 218-inch No. 6 Bagley & Sewall paper machine equipped with ANACONDA Brass Rolls. Built for the St. Regis Paper Company.

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# Surface-Active Chemicals in the Pulp and Paper Industry

H. A. LIPS

SURFACE-ACTIVE agents are relatively new chemicals available to the paper industry. The chief function of these compounds is to lower surface tension. In many cases this is an important problem to the industry and a problem, the details and theory of which, are rarely clearly understood. Before considering surface-active agents in greater detail, let us consider the effect which is called surface tension.

Webster describes surface tension as "that property, due to molecular forces, by which the surface film of all liquids tends to take a form having the least superficial area." We have all seen examples of surface tension. Water sprayed on wax paper assumes the shape of small balls. Raindrops are spherical in shape. These drops form into spheres because in this shape the mass has the least surface.

Surface tension may be demonstrated by carefully filling a glass of water above the lip. The surface tension of the water prevents the water from spilling until the glass is so full that the force of gravity overpowers the force of surface tension. Surface tension can also be demonstrated by carefully floating a steel needle on the surface of water. Because of surface tension water spiders are able to skate gracefully on the surface of water.

Surface tension is a measurable force. It can be measured by special devices constructed for this purpose. Since the forces involved are relatively small the physicist has established a special scale for measuring surface tension. The unit of measure is dynes per centimeter. A dyne is the force which, acting through 1 cm., will do the work equal to 1 erg.

Water has a relatively high-surface tension. In many cases this is an advantage, for instance, at sea, surface tension helps to keep the waves in check. In severe storms ships increase the surface tension by pouring oil on the water and in this way tame the waves. Surface-active agents, on the other hand, materially lower the surface tension of water. Lowering of surface tension promotes wetting, aids in detergency, promotes foaming, and assists in emulsifying.

### *Surface-Active Agents*

Since surface-active agents, due to the lowering of surface tension, assist in these properties of wetting, detergency, foaming, and emulsifying, they are often called by various names. "Wetting agents" are surface-active agents that primarily affect wetting. "Detergents" are always wetting agents, but not all wetting agents are necessarily detergents. Some surface active agents are, therefore, called "detergents." Others are called "foaming agents" because they excel in the property of producing foam. "Penetrating agent" is simply another name for a wetting agent. "Emulsifying agent" is the name given to the class of surface-active agents that are essentially used for producing emulsions. As little as 25 years ago the family of surface-active agents was more or less limited to soap and the sulphonated oils similar to turkey red oil. Since then a great variety of synthetic surface-active agents have been developed, many having specific properties for special uses. Research on synthetic agents is continuing unabated.

H. A. LIPS, Member TAPPI; Technical Laboratory, E. I. du Pont de Nemours & Co., Inc., Wilmington, Del.

Surface-active agents are chemical structures composed of two essential parts. One end of the molecule contains a highly mobile water-soluble radical. This is called the "hydrophile" and is said to have "hydrophilic properties." The hydrophile is repelled by waxes, fats, oils, and other nonpolar substances.

The other, the longer end of the molecule, contains a long chain that is water insoluble, and is repelled by water. This portion of the structure is attracted by fats, oils, and nonpolar substances. This part of the structure is the "hydrophobe" and is said to have "hydrophobic properties." It is assumed that surface-active agents form a film on surfaces.

In combining these two radicals together into a single molecule we obtain a surface-active agent. The degree of water solubility of the various possible hydrophile radicals varies. The longer the chain length of the hydrophobe the poorer the water solubility. One of the first considerations is, therefore, the selection of the proper balance to insure the necessary degree of water solubility. By varying the hydrophile and the hydrophobe, the properties of the surface-active agent are correspondingly varied. The inherent properties required of a hydrophile for producing a surface-active agent are: the power to solubilize the hydrophobe under a certain set of conditions such as temperature and electrolyte concentration. The inherent properties required of a hydrophobe are the ability to orient around nonpolar materials and surfaces, and to dissolve or be absorbed by oils, fats, waxes, and solvents to produce films, which are believed to be tough.

There are three distinct classes of surface-active agents and, of course, many variations within any given class depending upon the compromise properties of the hydrophile and the hydrophobe. These three classes are:

*1. Anionic Types.* The majority of the surface-active agents fall into this class. The anionic types carry a negative charge. They are, therefore, compatible with acid and direct dyes and will precipitate basic dyes. The hydrophile group is usually a sulphate, a sulphonate, or a carboxyl group. These groups are always anionic. This group of surface-active agents includes all of the soaps, sulphated oils, sulphonated hydrocarbons, and sulphated fatty alcohols.

*2. Cationic Types.* This class of compounds is generally composed of complex amines such as quaternary ammonium types. The cationic types, as the name indicates, have a strong positive charge. In general, they will exhaust on cellulose which carries a negative charge. This class of surface-active agents is compatible with basic dyes, but will precipitate acid and direct dyes.

*3. Nonionic Active Agents.* This class differs from the anionic and cationic types in that they do not ionize in solution. The hydrophilic radical is usually composed of polyglycols and polyhydric complexes. These types of surface-active agents, therefore, do not carry a charge and are compatible with both acid and basic dyes.

In each class of compounds the surface-active principle is the same. The hydrophobe surrounds the nonpolar body and attaches itself thereto. The hydrophilic portion points away from the nonpolar body toward the water phase and serves as the solubilizing group.

From the chart below you can see that the difference between soaps, fatty alcohol sulphates, and alkyl sulphonates is the difference in the hydrophilic group. This difference accounts for major variations in the properties of the compounds. The broken line in the structure represents varying chain

**Surface-Active Agents**

| *No.* | *Hydrophobe* | *Hydrophile* | *Name* | *Class* |
|---|---|---|---|---|
| 1 | $CH_3CH_2$..... | $CH_2COO—Na+$ | Soap | Anionic |
| 2 | $CH_3CH_2$..... | $CH_2SO_4—Na+$ | Fatty alcohol sulphate | Anionic |
| 3 | $CH_3CH_2$..... | $CH_2SO_3—Na+$ | Alkyl sulphonate | Anionic |
| 4 | $CH_3CH_2$..... | $CH_2HR_3 + Br -$ | Quaternary ammonium salt | Cationic |
| 5 | $CH_3CH_2$..... | $CH\,(O\,CH_2CH_2)_nOH$ | Polyethylene-oxide derivative | Nonionic |

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National Container Corporation.....Jacksonville, Florida
Southland Paper Mills, Inc. .....Lufkin, Texas
Champion Paper & Fibre Company.....Pasadena, Texas
Bedford Pulp & Paper Company, Inc. .....Big Island, Virginia
Hudson Pulp & Paper Company.....Palatka, Florida
B.F.D. Company.....Ogdensburg and Plattsburg, New York
Dexter Sulphite Pulp & Paper Company.....Dexter, New York
Alabama Pulp & Paper Company (St. Regis Paper Co.) Cantonment, Florida
St. Joe Paper Company.....Port St. Joe, Florida
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# SILICATE P's & Q's

For more information on these silicate uses ask for the file numbers.

USE-FILE #28-1

## Bleaching Wood Pulp

For peroxide bleaching of wood pulp "N" Silicate is used as a stabilizer. In one mill at 12% consistency and 1.5% peroxide the brightness increased 7 points on the GE meter. The fibre is cleaned as well as bleached by the process.

USE-FILE #28-9

## Reclaim Process Waters

In treating industrial waste waters activated silica sol is an important coagulant aid. In white water treatment and recovery, for instance, it has been found that alum supplemented with activated silica sol is from 3 to 20 times more effective than alum alone. Activated silica sols are made with "N" Silicate, reacted with various acid functioning chemicals.

USE-FILE #27-6

## High Wet Strength Paper

A new process impregnates paper with controlled amounts of silica by first spraying with dilute S* Special Silicate followed by dilute acid as it goes through the dryer. A 5% addition of silica yields an eight-fold increase in wet strength with no decrease in porosity.

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lengths which also affect the properties and the solubility of the product. The longer the chain length the lower the degree of solubility. It is possible to lengthen the chain to such an extent that the complex is no longer water soluble, but, of course, its commercial value is then limited. The lower chain length types are the wetting, emulsifying, penetrating, and foaming agents. The longer chain-length types having poorer solubility are frequently used as softening agents and lubricants.

Let us consider for a moment some of the classes listed in the table.

*Soap.* We are all familiar with ordinary soap. The soap industry is a tremendous industry and in this country alone soap manufacturers produce about 4 billion pounds of soap a year. Soap is precipitated by hard water because the calcium and magnesium salts which replace the sodium in the carboxyl group of soap are water insoluble. Soap is also readily precipitated by acids.

*Alcohol Sulphates.* These are made by replacing the carboxyl group in soap with a sulphate group. Since they are made from long-chain fatty alcohols by sulphonation they are commonly spoken of as "fatty alcohol sulphates." Fatty alcohol sulphates are not precipitated by hard water, in fact, the calcium and magnesium salts are not only water soluble, but are themselves excellent detergents. This type of surface-active agent is not precipitated by acids and retains its wetting and scouring properties in acid solution. They are slowly decomposed by hot acid solutions.

*Alkyl Sulphonates.* This class of compounds is similar in properties to the alcohol sulphate types, they are, however, resistant to hot acid solutions. In general they are not quite as good detergents as the alcohol-sulphate types, but are better wetting agents. They are also generally cheaper than the alcohol-sulphate types and foam somewhat less.

*Cationic Types.* If you examine formula No. 4 you will see that the long-chain portion is positively charged and the bromine ion is negatively charged. This arrangement accounts for the cationic charge of the molecule. Some of the cationic types are extremely stable in the presence of strong acids and strong alkalies. Some are destroyed by a high drying temperature. These types are substantive to cellulose and will exhaust on the fiber. They are frequently used on textiles as antistatic agents.

*Nonionic Types.* These are relatively new but are growing in importance. Since they do not ionize they are not limited by the charge on certain materials with which they may come in contact. They can be used as detergents in sea water and extremely hard water. There are also softening agents represented by this class of compounds.

*Surface-Active Agents in the Paper Industry.* Surface-active agents are becoming of increasing interest to the paper and pulp industries. They are used to increase the efficiency of firefighting sprays in the forest. In the manufacture of pulp, surface-active agents have been used in the digester to promote penetration of the cooking liquor into the chips. They have been used in the blowpit to assist in washing of the pulp, and to aid in emulsifying pitch so that it can be washed from the systems before it can contaminate the paper mill. They are used by the manufacturers of chemical pulps in the caustic extraction step to aid in removing calcium salts, pitch, and other resinous matters.

In the paper mill they have been found to be of assistance in wetting out bales of hard, dry pulp. They are used on the paper machine in absorbent papers as rewetting agents for improving the absorbency of the sheet and retarding the natural loss of absorbency due to aging. In this application the surface-active agent may be applied in the beater or by spraying on the surface.

Surface-active agents are also used as emulsifying agents. They are used in pitch removal to form temporary emulsions with an organic solvent such as kerosene, so that the kerosene will dissolve the pitch, and that it will remain dispersed and

stay with the sheet as it passes from the wire through the press section onto the driers. In this case the wetting agent simply acts as the emulsifying agent which keeps the pitch from agglomerating. Surface-active agents also serve to form emulsions of paraffin for wax emulsions used in beater and surface sizing of paper.

The detergent properties are taken advantage of in felt washing. These products are better felt-washing detergents than common soap. The wetting properties are used by mills to aid in wetting out and in some cases for breaking in paper mill felts. Today many manufacturers of paper mill felts incorporate a small percentage of a surface-active agent into the felt before it is shipped to the paper mills. This felt will wet out rapidly and uniformly. In this case the surface-active agent serves as a rewetting agent.

Surface-active agents are also used extensively in rag cooking and in the processing of waste paper. In rag cooking they are used to wet out the rags as they are loaded into the rotary. In this way it is possible to load a maximum charge into the digester. Many of the present-day rags contain wax emulsions and various other wax-type water repellents and finishing agents. A surface-active agent will aid materially in wetting out the rags, and will tend to emulsify the wax-type finishes so that they can be washed free. In this use it is generally advisable to add some surface-active agent to the washer as well as to the rotary.

The longer chain surface-active agents are also used to an appreciable extent in the paper industry. They may be surface or beater applied to soften the sheet or as the textile finisher prefers to call it, to improve the "hand." The cationic types, when beater applied, tend to exhaust and are, therefore, generally more effective in beater application. The anionic types are sprayed on the surface to improve the feel. These materials also find a use as lubricants for coating formulations. In this case they act as partial plasticizers for the coating adhesive and lubricate the coating as it passes through the supercalender.

In each of the uses that have been mentioned, there are specific requirements that depend upon the problem in question. There is no surface-active agent that will answer for all requirements. The requirements should be studied carefully and the surface-active agent that most nearly meets these requirements should be selected. The type and amount to use should be governed by the economics of the problem and the results desired. In general, additives are desirable. We know that raising the temperature aids detergency. We also know that we get better detergency in the presence of certain alkalies. In washing paper-mill felts we must balance the desirable detergency properties of the surface-active agent with the correct alkali and with temperature. We know wool will not stand high temperatures or strong alkalies. Our selection of a blend must be limited by these points. In deinking we know that a synthetic detergent will assist materially in removing dirt and ink. We also know that high temperatures and an alkali are necessary. Again a definite blend is much more effective than any one product alone.

We have discussed the effect of surface tension and the influence that surface-active agents have on this property. Surface tension plays an important role in the manufacture of paper. The place of surface-active agents in this industry is to lower surface tension. There is an equally important field regarding the opposite effect—trying to increase surface tension. This is the field of sizing, waterproofing, and water-repellent effects. This includes the effect of antifoams. This important phase of surface tension is mentioned since this paper has been concentrated on the lowering of surface tension with surface-active agents. These two effects combined indicate the importance of surface tension to the manufacturer of paper.

Presented at a meeting of the Delaware Valley Section of TAPPI, Philadelphia, Pa.

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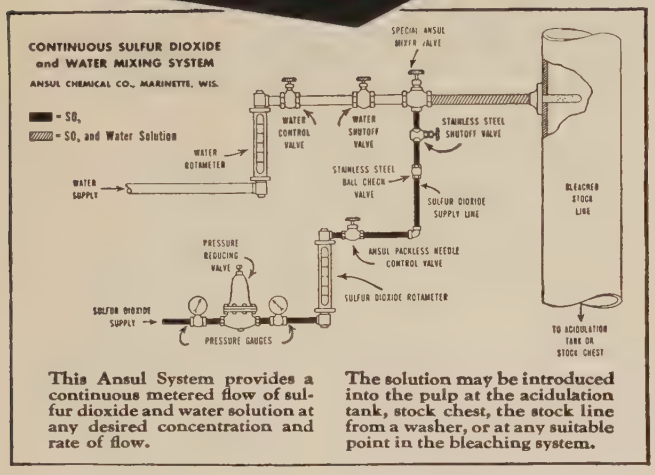


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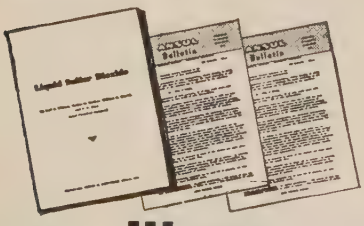

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# New Inks for the Graphic Arts

GEORGE CRAMER

THE IMINENT increased demand for new and better products on the part of the graphic arts in the past decade has made it necessary for the ink industry to revolutionize its formulations. These fundamental changes are going to require the paper industry's cooperation. As all know, speed and more speed has been the all-important password. The terrific demand for all kinds of printed articles ranging from food containers, display pieces, to magazines have meant changes in equipment, paper, and in ink.

The application of heat to the art of printing brought with it a new ink having as one constituent a high-boiling solvent. These inks were formulated to dry very quickly at elevated temperatures. The elevated temperatures meant added pieces of equipment on printing presses. It also meant special composition of the type of paper to be run. The development of the machine-coated type of paper was the direct outcome of this advance in the graphic arts process. Problems of many sorts have arisen with this type of heat-set ink, and in some instances even though the process continues many efforts are being made to circumvent it because of the many shortcomings and difficulties evident at present.

The paper industry well knows that some of the requirements which had to be met in making a paper for this type of ink have been rather severe and in spite of every effort which the paper industry has made to improve the situation, the printer is still pressed by many serious problems which he expects to avoid by considering still newer methods.

The headaches experienced in some of the heat applications for the ink drying lead the inkmaker to other avenues for producing inks that set quickly. This was accomplished by the use of moisture in one form or another. This type of ink has found considerable applications and fills a very definite need in many directions. It has, however, not been the answer to the problems as currently experienced by that part of the industry now resorting to the heat-set type. In the case of the moisture-set type of ink, paper has not been the element that was confronted as in the case of the development of heat-set types. Even so, problems have arisen in the application of this type of ink which have been principally caused by surface particles of either paper dust or paper coating.

The glycol solvents used in this type of ink seem to have a greater effect on paper softening than was originally anticipated. The graphic arts still not being satisfied was quick to look forward to still other possibilities in connection with the moisture-set type of ink. It was thought at one time or another that soluble protein materials used as a base might assist some in overcoming what difficulties were experienced in the original formulations. Further development is proceeding.

Papers having finishes or coatings of relatively high pigment content seem to be somewhat more satisfactory than those wherein the usual machine-coated stocks were experimented with. We doubt very much whether the paper industry became much involved in this endeavor, however, it is the speaker's impression that the paper industry could help considerably in the further development of printing of the moisture-set type of ink.

The printer's dream has, for a good many years, entailed the thought of making inks that dry quickly on the paper but do not dry on the press. An ink such as this is currently being made and developed. Apparently in this case the stock to be used is an important factor and in every instance we have found that the more highly coated stocks do a

GEORGE CRAMER, Director of Research, Sinclair & Valentine Co., New York, N. Y.

superior job. We doubt very much whether the industry would be required to make anything very special for this type of ink except that there is still a possibility that a machine-coated paper more nearly comparable to the regular coated would be a decided advantage. The ink industry still has in this case a few problems to be settled before this type of ink can be made to be really successful. Undoubtedly whatever improvements are to be made may have to be made in conjunction with the press builders rather than with the paper industry.

The advent of new plastics and new resins has opened up a wide field for new developments in inkmaking. The principal ones being those with a high-resin content having definite solvent qualifications. In this instance, combinations can be made of dispersed resins and dispersed plastics which happen to have good stability on the press and good printing qualities. However, at the moment there is still unavailable a proper type of paper which will allow this type of ink to get a more secure bind on the stock itself. In this combination of pigments, resins and plastics, the ink depends entirely on the nature of the coating of the paper for its binding qualities. There is, at the moment, no known stock that allows an ink of this nature to be adopted for general production purposes and the inkmaker hopes that the paper industry will oblige. It appears as though a paper coating or an uncoated paper having a film-forming base which could be annealed to the ink by reason of the type of solvent used in the ink itself would be needed.

The proper blending of paper and ink is one which cannot be emphasized too strongly particularly in view of the industry's objective. As we mentioned before, the objective is to be able to print faster and faster and at the moment it appears as though ink is one of those factors which is responsible for not being able to do so at these elevated speeds. It appears as though mechanical means such as heat, dampening, etc., are likely to be too slow, too expensive, and too sensitive to accomplish the objective and apparently mechanical means may have to be the method of approach. The smaller printer, of course, is still looking for the type of ink that does not necessarily have to be overly fast, but he is interested in some that might be developed by means of a reaction between the paper and the ink itself. The ink industry has on occasions made special inks which were practically nondrying and these inks when applied to surfaces such as cellulose acetate, cellulose nitrate, or even vinyl films practically dry almost immediately by the process of being absorbed. This absorption process is very similar to that currently employed in the printing of newspapers without its shortcomings. However, it is our impression that the paper industry might consider the possibility of using some such materials in their paper coatings as possible absorption media for inks of this special and plastic nature. Such paper coatings could be based on nitrocellulose, ethyl cellulose, ureas, melamines, and vinyls and thus be compatible with the ink involved.

There are still other types of inks wherein full advantage can be taken of penetration and absorption. In this case, the materials might be those that are completely soluble in any number of solvents or those in which an ink contains materials such as casein, various starches, methyl cellulose, CMC, and the like! For this type it is likely that a special paper containing an inner layer impervious to the water-based types in order to limit the degree of penetration and consequently the percentage of strike-through or show-through may be necessary. Inks of this nature could be made to operate at extremely high speeds without the use of other mechanical means such as heat, moisture, static, or ultra-violet. Most likely it might be necessary to consider the so-called wet-strength paper as a base even for coated papers rather than those currently in general use for this solvent type ink.

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a wax and resin carrier was run on a production basis. Here the thermoplastic-type inks used were heated in order to change them to the liquid form and thus make them of proper consistency for distribution on the press. A chilled paper was the medium used in this case to set the inks. It occurs to us as though a special type of paper probably more receptive to a formulation of such ink would have avoided the almost complete failure and abandonment of this type of printing.

The ink chemist's imagination carries him into fields which at the moment might almost be considered somewhat fantastic, but we believe that there are materials available today, or materials which may be developed in the near future, which could be set after printing by various chemical means, the chemical means either being incorporated in the paper or the paper being exposed to fumes or gases after application.

There is also a possibility of making ink formulations that could be coagulated by means of x ray or high voltages. The graphic arts industry has recently been introduced to a new process, a so-called xerography which depends essentially on the effects of static. At the moment this new process is still in its infancy but it appears, as heretofore, that special paper qualities may be necessary in order to make the process successful.

Our creative faculty once more leads us to the possibility of reactive types of papers, let's say, papers that would be more on the alkaline or acid side than those presently on the market. Thus, a resin could be used that would be precipitated by the alkalinity and in the other case a resin or plastic could be fixed by means of the acid. Our thoughts have been running a bit wild in our last remarks but imagination is the thing that leads us into further developments, as regards better inks and better papers for the graphic arts.

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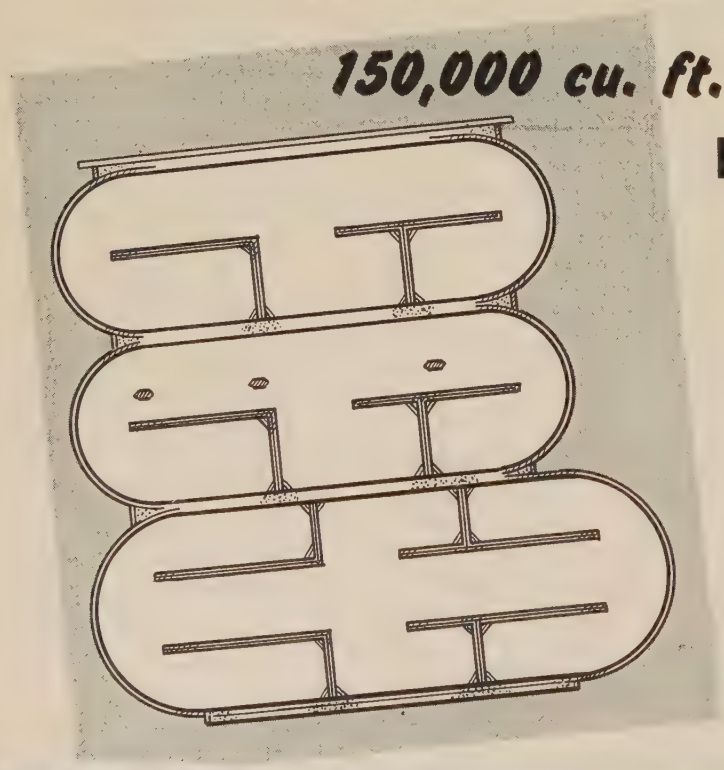
# Physical Factors Involved in the Clarification of Paper Mill Effluents

HARRY W. GEHM

The purposes of sedimentation devices or clarifiers as applied to paper mill overflow waters are to obtain as high a removal of settleable solids as is practical in a unit of reasonable size and to produce an underflow of sufficiently high concentration and low volume that it can be returned to the manufacturing process or dewatered to a degree consistent with disposal requirements. To be considered completely successful such a device must produce consistent results particularly in applications where reuse of either the overflow or underflow is practiced since the use of a water supply varying abruptly and continuously in suspended solids content is well nigh impossible and excessive underflow volume necessitates discharge of the excess, thus reducing over-all efficiency of the system.

All sedimentation devices operate on the principle of reducing the velocity of the liquid flow to a degree that the suspended matter desired to separate, settles by virtue of its greater gravity than the liquid in which it is dispersed. In general, sedimentation rates follow Stokes law, however, so many variables can exist in a sedimentation system and its operation, that are not accounted for in this equation, that its application is mainly of theoretical interest. Hence, design must be based on experience and a knowledge of all the im-

Harry W. Gehm, Technical Director, National Council for Stream Improvement, Inc., New York, N. Y.

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portant factors involved, and be integrated with the particular mill. Operation must be based on experience with a particular installation and its inherent peculiarities.

Sedimentation devices employed by the paper industry for clarifying white water or other mill waste as well as stock recovery fall into but three general classes despite the application of numerous shapes and varied appurtenances. These are the plain settling tank or basin, the mechanized clarifier, and the precipitator-type clarifier. The first of these, is generally cone or hopper shaped to facilitate collection and withdrawal of the underflow. The second type operates similarly but employs a sludge collecting or thickening mechanism and is generally circular or rectangular in shape. Some mechanized clarifiers also include a built-in flocculating mechanism. The precipitator type is arranged to support a blanket of thin sludge through which the overflow must rise and to which is attributed screening action. Some of this type contain collector mechanisms while others do not, but all employ built-in flocculation devices.

All types of devices attempt to achieve the same two basic things. They are as follows:

1. Achieve passage of the liquid through the unit at a uniform velocity with a minimum of disturbance to allow practically complete subsidence of settleable solids.
2. Collect, thicken, and remove the sludge at a rate high enough so that it does not interfere with sedimentation or slime up and can be discharged at a desirable consistency with respect to its disposition.

In considering either of these, selection of the type of device to be employed and its design are the first considerations if efficient and consistent operation is to be possible. In order that a satisfactory design be evolved and a practical method of operation established certain basic facts must be available to the engineer. These are as follows:

1. The flow rate as well as frequency and extent of flow variations of influent water.
2. If pumping and/or surge tanks are employed a knowledge of their operating characteristics is essential.
3. The suspended and settleable solids content of the feed together with the extent and frequency of variations.
4. Character of the suspended solids in relation to sedimentation and thickening.
5. If coagulants are to be employed or not and if so which ones and in what dosages.
6. Frequency and range of temperature variations.
7. The presence of dispersed or dissolved gases in the effluent.
8. The putrescibility of both the suspended solids and liquid portions of the influent.
9. If reuse of the water is contemplated a knowledge of demand rates and the minimum acceptable quality and allowable quality variations is necessary.
10. If reuse of the underflow is contemplated the maximum volume acceptable to the mill must be known and variations in demand for it determined.
11. If underflow disposal is considered, the method for further thickening or dewatering must be established and operating cycles projected.

Of all these factors perhaps the most important is the flow in relation to settling unit selection and design since effective results cannot be obtained if tank velocities exceed the limits at which particle subsidence will take place. The application of these devices to paper mills has been rather unsatisfactory in a number of cases either because of underdesign on the flow basis or flow irregularity. Underdesign is readily corrected by the installation of sufficient capacity, costly though it may be, but variations are not so easily handled and unfortunately these must generally be dealt with in the paper industry. Considerable improvement in results can often be obtained, if the effluent is pumped, by designing pumping stations in a manner which will serve to smooth out normal variations in flow rate. Under some conditions changes within the mill can go far in smoothing out discharge fluctuations. Surge

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tanks can be employed successfully in some instances. However, size limitations and the necessity for preventing settling and decomposition of the effluent limit their application. A recent method of interest is the return of effluent, or in the case of precipitation-type clarifiers, the return of blanket sludge to the influent to equalize the flow. Intermittent operation is to be avoided if at all possible, both because of the larger equipment capacity requirement resulting from the down-time involved and the disturbance created by abrupt starting.

When wide flow variations cannot be dealt with outside the unit particular care must be paid the design of influent and effluent appurtenances so that the greatest degree of stilling is produced in the influent, disturbance is minimized, and short circuiting does not occur. Under such conditions the simpler types of tanks operated at low overflow rates appear most successful. This would be anticipated since maximum velocities will be lower and, assuming good distribution of flow within the tank, more space for the dissipation of the kinetic energy delivered is provided. In this manner also less disturbance of particles subsiding results than in high rate units. The sludge blanket needed for high rate operation is sensitive to flow changes, and disturbance resulting in effluent deterioration is a common occurrence. The extent of deterioration is much greater than that which would occur in a low rate unit due to the relatively high solids concentration of the blanket. If the effluent is reused the results of such an upset can seriously hamper mill operations or if discharged direct to a stream can add considerably to the suspended solids loading. Hence, it is imperative that effective means be taken to integrally compensate for fluctuating flows if the precipitator type unit is to be successfully applied under variable flow conditions.

The suspended solids present in paper mill effluents can be divided into two general classes with respect to clarification. The first are the settleable solids and can be defined as those subsiding when a sample of the discharge is allowed to settle quiescently in a large container for a period of 2 hours. Nonsettleable, the second type, are those which remain suspended in the supernatant after the same period of settling. Since chemical coagulation converts nonsettleable solids to settleable ones and generally adds to the settleable solids content by virtue of hydration of the chemical employed, settleable solids in a coagulated clarifier feed can be defined as the solids settling in 2 hours after treatment with an effective chemical dosage.

Since none but settleable solids can possibly be removed in a clarifier the best index of performance becomes the ratio of the portion removed by the unit to the concentration present in the feed. Knowledge of the quantity of settleable solids to be handled must be known so that adequate clarifier space can be provided for them on subsidence so that they are removed from the zone of active settling in the tank and can remain quiescent sufficiently long for compaction to take place. Irregularities in solids feed are not of particular importance to clarifier design unless they are extremely great. Generally, measures can be taken within a mill to prevent concentrations from exceeding reasonable limits over periods of sufficient duration to affect adversely clarifier operation. Fluctuations of from 1 to 5 pounds per thousand gallons can generally be handled without difficulty if good operational control is provided. Early difficulties caused by solids variations experienced with precipitator type units have been largely overcome. Thus this matter is much more an operating than a design problem irrespective of the type of clarifier employed.

The character of the suspended solids is very important from both the standpoint of design and operation. Particle size, nature, mass, and degree of hydration are all involved. Light hydrous pulp solids such as those found in tissue and glassine white waters subside at lower velocities than the coarser and heavier solids found in board mill effluents or those

containing pulps and attached fillers. In general, chemicals employed for coagulation form water swollen agglomerates of lower subsidence rate than coarser untreated settleable particles. Hence, lower overflow rates must be provided when naturally light or fine solids are to be handled, or coagulation practiced, than when coarser heavier pulps are handled. As the more hydrous solids compact more slowly and to a lesser ultimate degree than heavier types, greater provision must be made for their storage during the compaction period. Collection requirements also vary with solids character. Rotating rakes or flights can be successfully applied to heavier solids but have been found ineffective with lighter varieties. When mechanical collectors are employed with sludges high in fillers and capable of dense compaction, care must be taken to embody overload features and operation must be adjusted so that extreme densities are not encountered since they can damage the mechanism. Likewise, collector mechanism operation must be adjusted to light pulps so that it does not interfere with, rather than aid thickening. With light pulps, periodic rather than continuous collector operation generally produces best results.

When intermittent underflow relief is practiced, a surge tank must be provided, particularly if underflow is reused, so that a supply is available when the mill can use it. Such a surge tank must be sufficiently large to prevent overflow but not allow long periods of holding or "hang-up" of a portion of the slurry since such conditions promote sliming. Serious consideration should be given the replacement of slurry surge tanks with external thickeners. These will allow simpler clarifier operation, provide greater thickening, prevent long slurry detention, and do not add greatly to over-all cost.

Alum is the most widely used and most effective coagulant for white waters per unit cost. It is sometimes supplemented with lime or activated silicates to weight the floc or adjust the pH and alkalinity. To be of greatest over-all effectiveness, the minimum dosage necessary to completely clarify the water is recommended. Excessive alum produces a light floc of poor settling and compacting qualities, a slow gelatinous sludge, and carries over in solution in the overflow causing difficulties on reuse or turbidity in the receiving stream. The character and concentration of dissolved solids, the pH, and alkalinity determine the alum requirement rather than suspended solids concentration for most white waters. Control is not easily accomplished as no one quick and simple test can determine the coagulant demand. At the present time pH is used with some success and is certainly a better expedient than setting the alum feed at the maximum observed requirement. Investigation of this matter looking toward a determination which is adaptable to automatic recording and feed adjustment is in order.

Change in feed temperature can cause considerable upset in any type of sedimentation unit. Since the density of water changes with temperature, introduction of feed in variance with tank temperature causes currents in the tank which can interfere with subsidence, cause short circuiting, or upset filtering blankets in precipitator type units. The higher the overflow rate of a clarifier, the more sensitive it is to temperature change. This difficulty is frequently encountered. It can sometimes be overcome by regulating individual discharges or making other changes in the paper mill. General flow regulation helps as does integral regulation by returning a percentage of tank contents to the feed. If it appears that this factor must be dealt with, overflow rates should be reduced well below the normal maximum if an operable system is to be obtained since large tank capacity in relation to flow tends to reduce temperature effects.

Air dispersed in white water can cause flotation of solids resulting in serious operating troubles. This has its source in the paper machines and savealls. It can also result from leakage at pumps. Some clarifiers come equipped with deaerating devices which are very effective in preventing flotation troubles and a number of simple deaerating methods can


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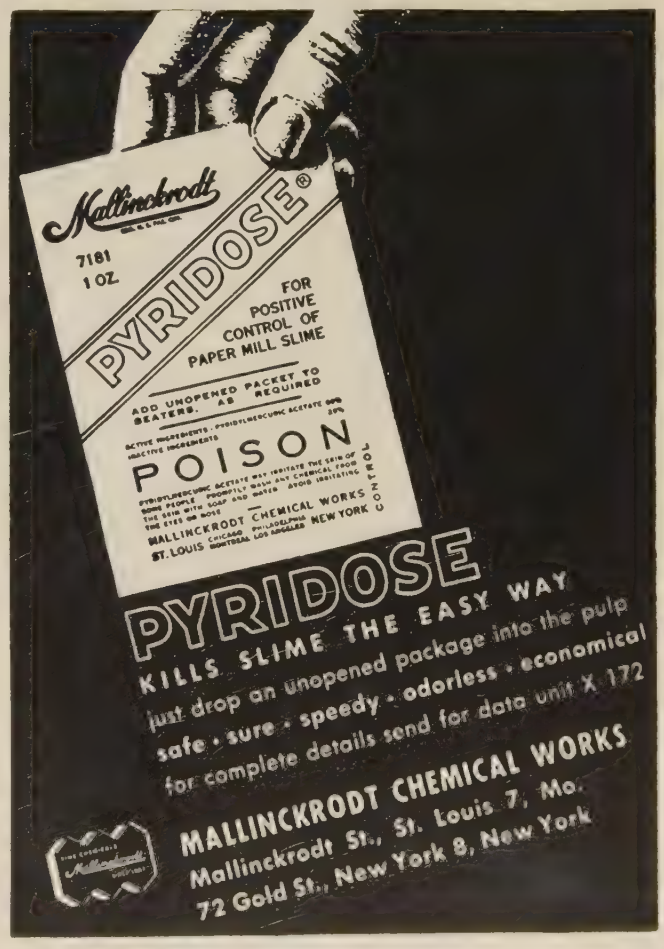
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be employed to remove dispersed or dissolved gases to a satisfactory level at little cost.

The rapidity with which bacteria grow and cause slime or putrescence in white waters is an important factor in both the design and operation of clarifier installations. Rapidity of growth depends mainly upon temperature and the presence of rapidly decomposable substances such as glues, starches, sugars, etc. Bacteria are always present and given proper conditions will multiply rapidly. It is therefore important that both the over- and underflows not be held unduly long and that dead areas in clarifiers be nonexistent particularly when waters high in dissolved organic matter, such as news and chip white water is handled. It is also important that sludge removal be as complete as possible and that internal parts be designed so that sludge does not deposit on them and remain to decompose. One of the most important functions of collectors is to keep the slurry moving progressively through the tank. When hopper bottoms are employed the sides should approach 60° from the horizontal in angularity since most sludges will not slide down a lesser incline and must be moved manually. Difficulties resulting from bacterial growth in a clarifier can be carried to the paper mill with dire results. In handling this problem where it exists a page may be borrowed from sewage clarification in which partial chlorination of the clarifier feed has been found effective in controlling decomposition. This may work equally well with white waters.

Failures in the use of clarified white waters appear to stem mainly from lack of consistent effluent quality. It is mandatory in most cases, and preferable in any instance, that overflow waters so used be substantially free of suspended solids and certainly contain no coarse material. In some uses such as for high-pressure showers the suspended solids content must be extremely low, but for others this requirement is not so exacting. For this purpose clarified water is generally filtered but for others good quality effluent (under 50 p.p.m. fine suspended solids) is generally satisfactory. A well-designed, integrated, and operated system should be able to meet this requirement continuously. However, as a precautionary measure it is advisable to place a diverting box in the return line leading to the clear water storage tank equipped with a discharge valve actuated by a turbidity indicating device so arranged that unacceptable effluent will be sewered or returned to the influent.

Disposal of white water residues is generally accomplished by lagooning the underflow or dumping it after dewatering. In either case high consistency is necessary or at least preferable. Vacuum filtration requires a minimum consistency of 5% for good operation and, to a certain point, filter loadings increase with the feed consistency. Hence, the thicker the underflow discharged to the filter the smaller the unit needed or the shorter the operating period necessary. It is obvious then that filter station design and operation is contingent upon clarifier unit performance.

The observations set forth above represent the compilation of factors involved in a paper mill's obtaining and maintaining a satisfactory functioning clarifier system which, on the surface, may appear a simple matter. Actually it is anything but that, for added to the above factors are the further complications attending grade changes and wash-ups. Despite all that is involved considerable progress has been made in recent years in improving the design and application of this system by equipment manufacturers, engineers, and the mills themselves. Two general means for improvement in this application by the mills exist. One is that, in acquiring equipment, cost be placed secondary to sound engineering and that more skilled time be allocated to operation. If these principles are followed the results obtained from the standpoint of savings in heat, fiber, and water as well as stream improvement are most likely to be well worth the effort and will justify the cost.

Presented at the Annual Meeting of the Technical Association of the Pulp and Paper Industry, New York, N. Y., Feb. 20–23, 1950.

# Formulation and Properties of Laminating Varnishes

C. B. BENNETT

SYNTHETIC RESIN bonded laminates have been produced for over 30 years, and some of their general properties and uses, especially in the electrical industry, are known to many in the paper industry. The properties of the varnishes used in laminating are probably less familiar. A description of varnish properties is, therfore, the primary purpose of this paper, but varnish formulation will also be discussed in a general way since specific properties result largely from the formulation. First, an attempt will be made to present the properties desirable in any varnish for conventional laminating, and then the specific varnish properties necessary for each general type of laminate will be indicated.

The conventional laminating varnish is a solution of a thermosetting resin in water or water and a solvent, such as ethyl alcohol. Although various types of cotton, asbestos, or glass cloths are regularly used as base materials for laminating, paper is used in the largest volume, and the varnish properties discussed will therefore specifically apply to paper-base laminates bonded with phenolic, urea, or melamine varnishes.

Several properties are necessary for any varnish to be useful in conventional laminating:

1. Reasonable stability to permit shipping and storage. (At least one month at 25°C.)
2. Relatively low viscosity for ease of handling and good penetration. (Maximum about 10 poise at 25°C. for 50% solids).
3. Absence of excessive odor or toxicity.
4. Reasonable cure or set time. (Laboratory test indicating press cycle necessary when laminating.)
5. Solids of at least 50% to minimize shipping costs and permit attainment of high-resin content in paper without repeated dipping.
6. Reasonable cost.

Other properties desired will vary with the type of laminate being fabricated. Most laminates may be classified roughly as either mechanical, electrical, punching, or decorative, and the varnish properties required for each of these general grades will be briefly outlined:

Mechanical grade varnishes are for laminates used mainly in structural applications. Here the emphasis is on the penetrative qualities of the varnish, short cure time, and low cost. A phenolic varnish is generally used on a kraft-paper base and the resin should be a relatively low polymer (i.e., have a low-inherent viscosity) so that deep penetration with corresponding excellent dimensional stability will result. The degree of dimensional stability to be expected is indicated by A.S.T.M. water absorption tests wherein pieces $^1/_8$ by 1 by 3 inches of a test laminate are immersed in water at 25°C. for 24 hours. Water absorption of less than 1.5% is generally desirable, and the edge swell of the piece should be less than 3%. The use of a strong alkaline catalyst and the proper mole ratio (molecular ratio of phenol to formaldehyde) for the reaction brings about the short cure time and correspondingly short-press cycle desired. This type of formulation also yields excellent conversion of raw materials to resin solids, and this factor plus the use of a minimum amount of nonaqueous solvent leads to low cost. Other properties sometimes desired in mechanical grade laminates are absence of odor and light color. Constants for a typical mechanical grade varnish are given in Table I.

For electrical-grade laminates, phenolic varnishes are also specified, but alpha-cellulose paper is used as the base and the requirements are even more specific than for mechanical grades. Electrical-grade laminates are used as panel boards and for hundreds of parts in electrical and electronic equipment, and must therefore be good insulators. The various

C. B. BENNETT, Catalin Corp. of America, New York, N. Y.

Table I

| | Mechanical | Electrical | | Punching | Decorative | |
|---|---|---|---|---|---|---|
| | Laminate desired | | | | | |
| Resin type | Phenolic | Phenolic | Cresylic | Phenolic | Phenolic | Melamine |
| Viscosity, 25 °C., poises | 5.0–7.0 | 1.25–2.50 | 3.0–6.0 | 2.5–5.5 | 50–125 | 0.75–1.0 |
| Specific gravity, 25 °C. | 1.16–1.17 | 1.06–1.07 | 1.02–1.03 | 1.01–1.02 | ..... | 1.15–1.158 |
| pH | 8.0–8.5 | 6.5–7.5 | 4.5–6.5 | 5.0–6.0 | 4.4–4.9 | 9.3–9.6 |
| 135 °C. cure time, sec. | 400–600 | 500–800 | 600–900 | 900–1200 | 600–900 | 600–700 |
| ASTM solids, % | 58–62 | 50–54 | 54–58 | 53–57 | 70–74 | 48–50 |
| APHA color | ..... | ..... | ..... | ..... | <100 | <100 |

NEMA grades for these laminates specify maximum values for water absorption, power factor, and dielectric constant and a minimum value for dielectric strength. For some work, the laminator's customer may also specify values for these constants after 24 or 48-hour immersion in water. Government specifications sometimes include dielectric strength parallel to the grain, surface resistivity, insulation resistance, etc. For electrical-grade phenolic laminating varnishes, it is therefore necessary to further narrow the varnish formulation and properties. Strong alkaline catalysts must be replaced by ammonia or amines that are less conductive catalysts. For the grades with most exacting requirements (XX and XXX) phenol must be replaced by cresols and xylenols. These two formulation changes just mentioned yield resins that are generally less hydrophylic requiring more nonaqueous solvent to obtain a varnish with good stability and low viscosity. Cure times of these varnishes need to be longer to permit the extended flow and excellent penetration that are both necessary if a laminate with low-water absorption and power factor is to result. The formulation of a varnish for XXX grade laminates requires careful balancing of the phenols used, the mole ratio, and the reaction cycle. Extensive checking and testing are necessary to develop an ideal electrical grade varnish, and careful production control is, of course, necessary also. Constants for typical phenolic and cresylic electrical-grade varnishes are given in the table.

Punching grade varnishes are also generally phenolic and are used with alpha-cellulose or various higher strength papers, such as rag or bleached kraft. The resin qualities permitting clean punching of resulting laminates are strength, elasticity, and softening with heat (for hot punching). These resin qualities are usually obtained by reaction with drying oils or addition of other special plasticizers. Most pieces punched from these laminates are for electrical applications, and the same characteristics as for electrical grade laminating varnishes must also be incorporated. Plasticizers used must, therefore, have as little polarity as possible, have low-water solubility and affinity for water, and be compatible with the phenolic resin even in the cured state. In addition to these requirements, the plasticizer must not migrate to the surface and cause tackiness, nor can it yield a laminate that will stick to the punch. The range of plasticizers that are appropriate is, therefore, quite narrow. Constants for a typical punching grade resin are given in the table.

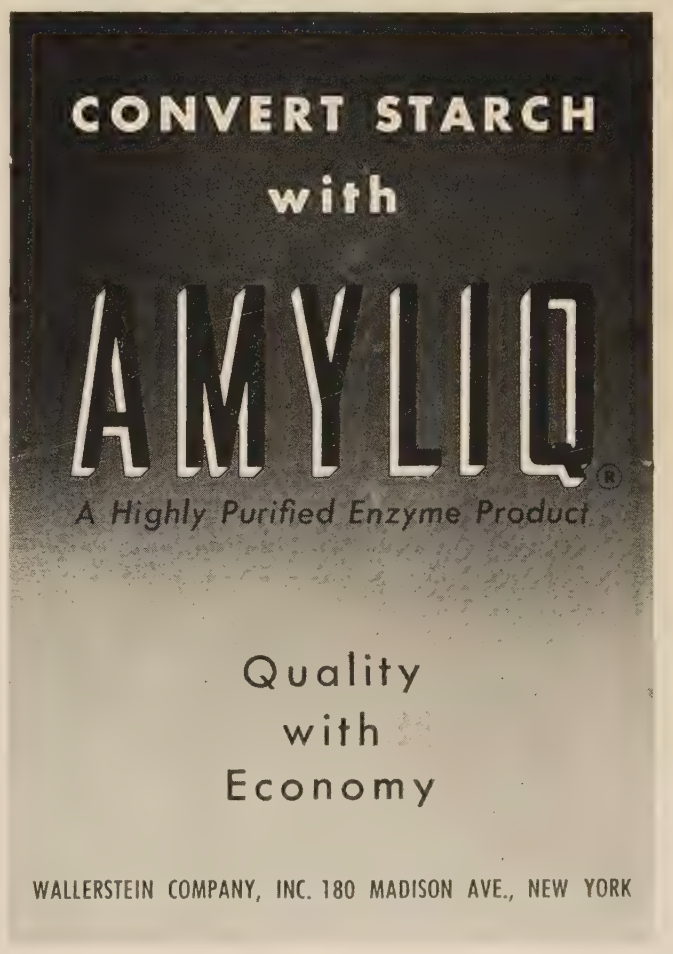
For decorative grade laminates phenolic, urea-melamine, or melamine varnishes are generally used with pigmented or printed alpha-cellulose paper for a number of applications of which the best known is, of course, the surface sheet on table-top laminates. Decorative varnishes may be made with strong alkaline catalysts since the electrical properties of the laminate are not a factor. Although phenolic decorative varnishes serve admirably for dark colors, their use for pastel shades is not completely satisfactory since their light stability is only fair. For these light colors, urea-melamine varnishes were used for some time, but melamine varnishes have now replaced them almost completely since the melamine varnishes are superior in water, heat, and abrasion resistance. All of these varnishes must be made with raw materials passing rigid color tests and are manufactured in nickel or glass-lined kettles. Constants for a phenolic and a melamine varnish are given in the table.

Varnishes for such specialized purposes as postforming, low-pressure laminating (phenolic type) and impregnation of paper (without pressing) for moisture and chemical resistance are usually modifications of mechanical or electrical grade varnishes to meet specific customer requirements. These modifications may involve the use of analine, resorcinol or high-molecular weight phenols or possibly furfural, butyraldehyde, and other aldehydes. As would be expected, drastic price reductions in any raw materials of the phenolic, amine or aldehyde type result in a re-evaluation of their use in laminating varnishes.

Successful laminating varnish suppliers all manufacture their products to meet specific customer requirements and pass rigid physical tests such as those shown in the table, but the fabrication of a laminate of high quality requires the correct base paper and optimum impregnation and curing conditions as well.

Wise decisions as to paper, resin, and laminating conditions involve close contact and mutual trust between buyer and seller. A complete survey and discussion of the conditions and technical problems involved with both the paper and resin suppliers' representatives will be of valuable aid in the development or improvement of any laminate.

Presented at the Annual Meeting of the Technical Association of the Pulp & Paper Industry, New York, N. Y., Feb. 20–23, 1950.



# Instrumentation Studies LVII. Equilibrium Relative Humidities Above Saturated Salt Solutions at Various Temperatures

W. A. WINK and GEORGE R. SEARS

**This report presents new data for a number of saturated salt solutions employed in maintaining constant relative humidity in essentially moisture-tight enclosures. The equilibrium relative humidity and the vapor pressure of saturated solutions are given for three temperatures—namely, 73, 86, and 100°F. For the readers' convenience, charts showing the dependence of the relative humidity on temperature are presented so that the equilibrium relative humidity over a saturated solution may be obtained for any temperature between room temperature and 100°F.**

THE USE OF saturated salt solutions as a means of providing constant relative humidity in an enclosed space has found increased applications, many of which require the conditioning of an atmosphere to a definite relative humidity as well as to a given temperature. In testing procedures where a wide range of humidities are required, such as the determination of sorption isotherms of foods or cellulosic products, the determination of water-vapor permeability, or the determination of hygroexpansivity of papers and other sheet materials, saturated solutions are particularly useful for providing a constant relative humidity. A further important application is found in the field of hygrometry where the calibration of the recently developed electric hygrometer in atmospheres conditioned to different relative humidities with saturated solutions is appreciably simplified.

For most salt solutions, the relative humidity is dependent upon temperature; at present there are insufficient data available in the literature to allow selection of saturated solutions suitable for maintaining a broad range of relative humidities at various temperatures. Handbook tables of solutions for maintaining constant humidities are, as a rule, inadequate. Usually, the equilibrium relative humidity over a solution is given for only one temperature; the temperature is not the same for all solutions and is frequently unsuitable for the work at hand.

During the course of other work at the Institute, dewpoint determinations of the equilibrium relative humidities over several saturated salt solutions have repeatedly differed from handbook values. In order to examine these discrepancies and to obtain more complete data, a different method was used in this study of seventeen saturated solutions at three temperatures in a range in which it was believed conditioning problems would most frequently be encountered.

W. A. WINK, Member TAPPI; Technical Associate, and GEORGE R. SEARS, Member TAPPI; Research Associate, The Institute of Paper Chemistry, Appleton, Wis.

## APPARATUS

Of the methods available for the determination of the relative humidity over a saturated salt solution, the measurement of the vapor pressure of the solution appeared to be most accurate. This method directly measures a fundamental quantity involved in the concept of relative humidity, which is defined in the present work as the ratio of the actual water-vapor pressure in any space to the pressure of saturated water vapor at the same temperature. A schematic drawing of the vapor-pressure apparatus is shown in Fig. 1; with the exception of slight modifications, it is essentially the same as that used by other investigators (*1*).

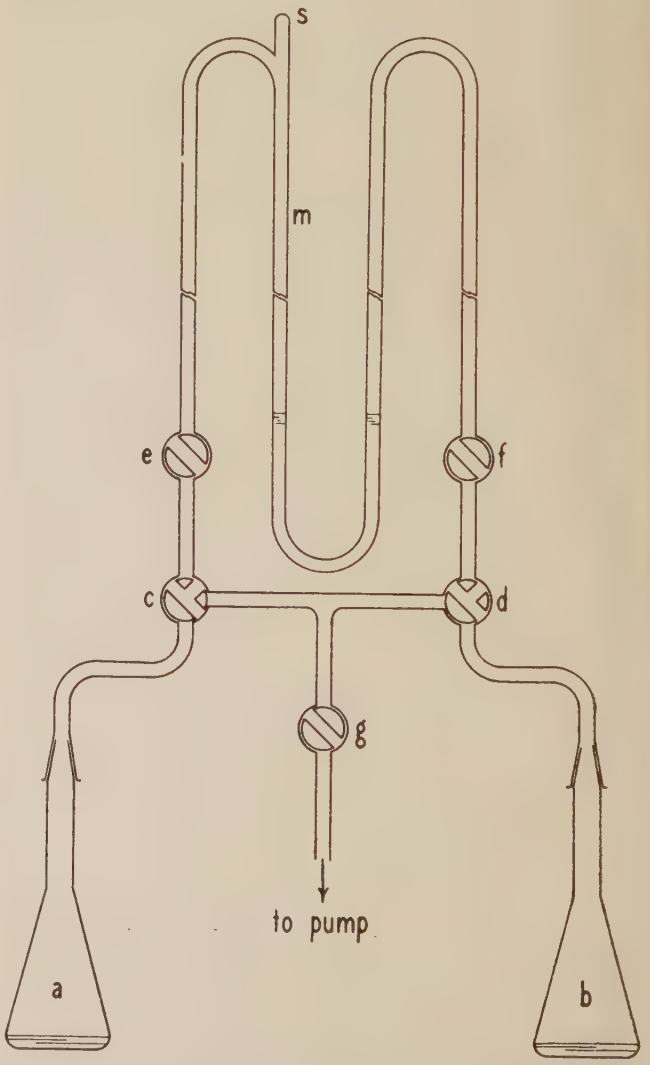



*Fig. 1. Schematic diagram of apparatus for vapor-pressure determination*

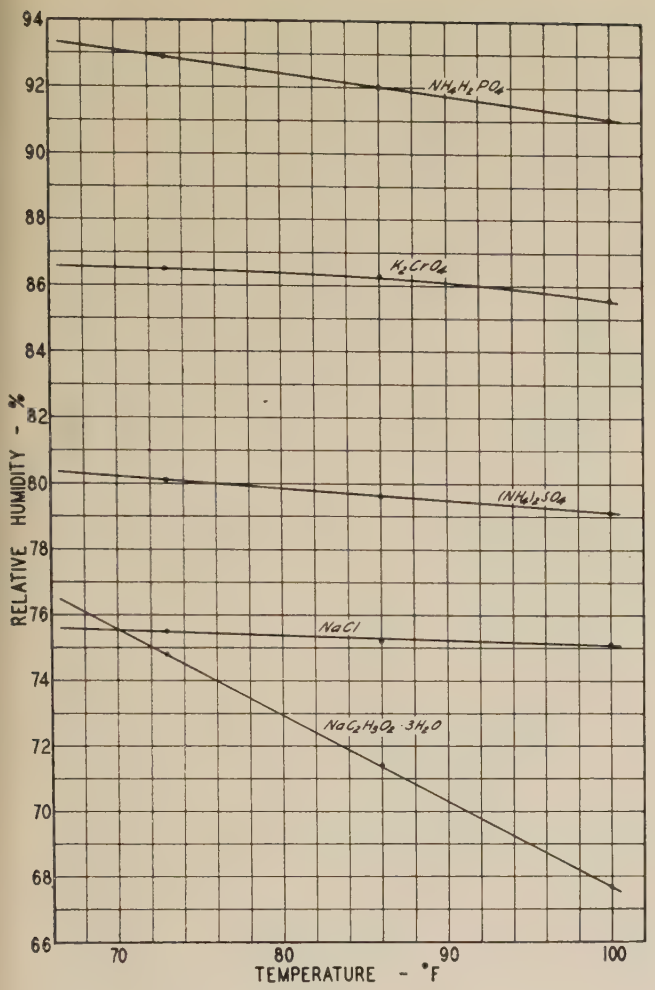



*Fig. 2. Variation of equilibrium relative humidity with temperature over saturated salt solutions*

The apparatus was of glass construction with the parts so oriented with respect to each other as to permit immersion of the two flasks (a and b) in a constant temperature water bath. In order to prevent condensation of vapor in any part of the system not in the water bath, the room temperature was maintained at a constant value greater than that of the water bath. The bath was enclosed in a thermally insulated housing and was provided with a cooling coil, a knife-type heater, a stirrer, and a mercury thermoregulator. Water at a temperature lower than that at which the bath was maintained constantly flowed through the cooling coil and the temperature of the bath was therefore regulated through the thermoregulator by the off-on operation of the knife heater. The variation of the bath temperature for any setting of the thermostat was less than 0.02°C. as indicated by a Beckmann thermometer.

The liquid used in the manometer (m) was an oil (Amoil-S, manufactured by Distillation Products Inc.) having a density of 0.915 gram per ml. at 100°F. It was specially heat treated under a vacuum before being transferred to the manometer through the seal-off (s) to remove dissolved air which might otherwise have caused difficulty and inaccuracy in the ensuing vapor-pressure determinations. The manometer was read to the nearest 0.5 mm. of oil, which corresponds to 0.034 mm. of mercury at 0°C. A Cenco Hyvac pump was used in evacuating the system.

In the determination of vapor pressure, the apparatus could be used in different ways. The vapor pressure of a saturated solution could be compared directly with that of water by placing water in one of the flasks and the saturated solution in the other, and turning the valves c and d to connect each leg of the manometer to the corresponding flask. Alternatively, the flasks could be connected to the manometer separately and the vapor pressure for each determined directly. The first mentioned procedure is the more dependable if the temperature and the oil density are not accurately known; however, if they are accurately known, the latter method is preferred because it permits the simultaneous handling of two solutions. In the early work, the two methods were compared and, since good agreement was obtained, the latter method was used to obtain the data presented in this report.

## PROCEDURE

Normally, the manometer was under vacuum; the stopcocks e and f were closed whenever it was necessary to let air into the other part of the system.

Approximately 20 ml. of a saturated salt solution containing a slight excess of the salt were placed in one flask. A similar quantity of another solution or of water was placed in the second flask. The flasks were then immersed in the constant temperature bath and connected to the vapor-pressure apparatus. By opening stopcocks c, d, and g, a connection to the vacuum pump was established and evacuation was started and continued for a period of approximately 30 minutes to remove the dissolved gases in the solutions. At the

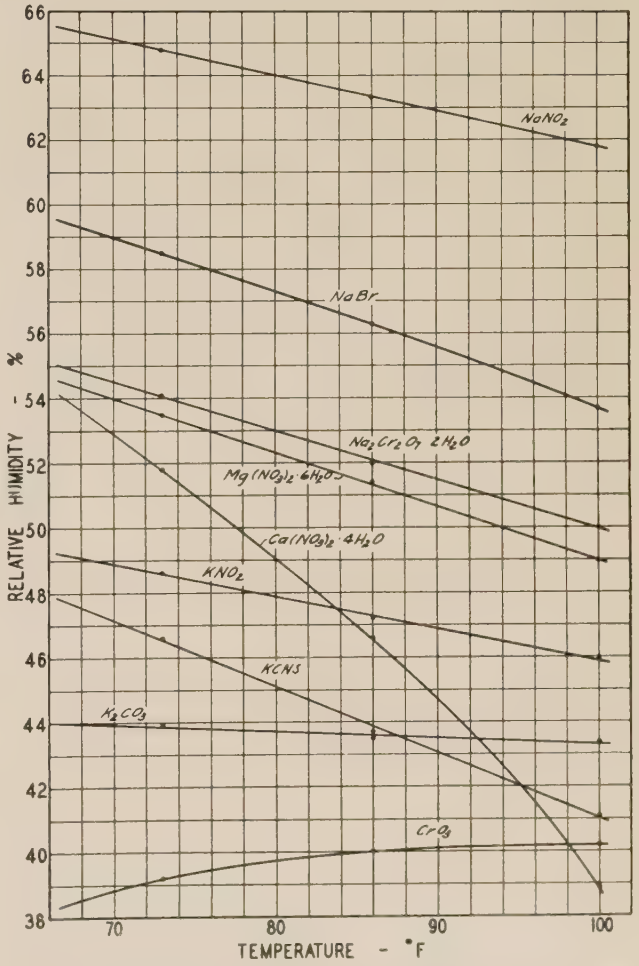



*Fig. 3. Variation of equilibrium relative humidity with temperature over saturated salt solutions*

Table I. Relative Humidity and Vapor Pressures Over Saturated-Salt Solutions

| Chemical | Formula | 73°F. V. P. | 73°F. R. H., % | 86°F. V. P. | 86°F. R. H., % | 100°F. V. P. | 100°F. R. H., % |
|---|---|---|---|---|---|---|---|
| Water | $H_2O$ | 20.79 | ... | 31.82 | ... | 49.10 | ... |
| Ammonium monophosphate | $NH_4H_2PO_4$ | 19.32 | 92.9 | 29.27 | 92.0 | 44.72 | 91.1 |
| Potassium chromate | $K_2CrO_4$ | 17.98 | 86.5 | 27.47 | 86.3 | 42.05 | 85.6 |
| Ammonium sulphate | $(NH_4)_2SO_4$ | 16.65 | 80.1 | 25.32 | 79.6 | 38.85 | 79.1 |
| Sodium chloride | NaCl | 15.69 | 75.5 | 23.94 | 75.2 | 36.88 | 75.1 |
| Sodium acetate | $NaC_2H_3O_2 \cdot 3H_2O$ | 15.56 | 74.8 | 22.72 | 71.4 | 33.23 | 67.7 |
| Sodium nitrite | $NaNO_2$ | 13.47 | 64.8 | 20.15 | 63.3 | 30.33 | 61.8 |
| Sodium bromide | NaBr | 12.16 | 58.5 | 17.93 | 56.3 | 26.37 | 53.7 |
| Sodium dichromate | $Na_2Cr_2O_7 \cdot 2H_2O$ | 11.24 | 54.1 | 16.56 | 52.0 | 24.56 | 50.0 |
| Magnesium nitrate | $Mg(NO_3)_2 \cdot 6H_2O$ | 11.13 | 53.5 | 16.34 | 51.4 | 24.06 | 49.0 |
| Potassium nitrite | $KNO_2$ | 10.10 | 48.6 | 15.03 | 47.2 | 22.53 | 45.9 |
| Calcium nitrate | $Ca(NO_3)_2 \cdot 4H_2O$ | 10.77 | 51.8 | 14.83 | 46.6 | 19.11 | 38.9 |
| Potassium thiocyanate | KCNS | 9.68 | 46.6 | 13.92 | 43.7 | 20.17 | 41.1 |
| Potassium carbonate | $K_2CO_3$ | 9.12 | 43.9 | 13.85 | 43.5 | 21.32 | 43.4 |
| Chromium trioxide | $CrO_3$ | 8.16 | 39.2 | 12.74 | 40.0 | 19.73 | 40.2 |
| Magnesium chloride | $MgCl_2 \cdot 6H_2O$ | 6.83 | 32.9 | 10.32 | 32.4 | 15.65 | 31.9 |
| Potassium acetate | $KC_2H_3O_2$ | 4.76 | 22.9 | 6.99 | 22.0 | 10.00 | 20.4 |
| Lithium chloride | LiCl | 2.31 | 11.1 | 3.56 | 11.2 | 5.47 | 11.1 |

end of this period, the three-way stopcocks c and d were turned to a position so that (1) the connection between the flasks and the vacuum line was broken and (2) a connection between the manometer and the vacuum line was established. Stopcock g was also closed momentarily at this time to permit removal of a drying tube which was in the vacuum line only during the foregoing phase of the test. After a brief pumping, stopcocks e and f were opened, thereby connecting the manometer (which was normally under a vacuum) to the vacuum line. Following an interval of approximately 30 minutes, during which time the solutions were allowed to reach the temperature of the bath, the determination of the vapor pressure of the solution in either flask a or b was started. For the purpose of this discussion it is assumed that the vapor pressure of the solution in flask a was measured first. The three-way stopcock c was turned to connect the flask a to the left limb of the manometer and disconnect it from the pump; the other limb of the manometer was left connected directly to the vacuum line. At about 30-minute intervals following the connection of the flask to the manometer, readings (at least two) of the vapor pressure (in millimeters of oil) were taken. The readings served a two-fold function in that a check on the equilibrium condition of the system as well as a check on the manometer readings was obtained. An air leak or an unstable temperature condition in the apparatus would be detected by observing a change in successive readings. This concluded the vapor pressure determination of the solution in flask a. To determine that in flask b, a corresponding procedure was used.

## RESULTS

The vapor pressure and the relative humidity obtained for a series of saturated salt solutions at three temperatures—namely, 73.0, 86.0, and 100°F.—are presented in Table I. The values represent the average of two separate determinations on solutions prepared from C.P. grade chemicals with distilled water. The vapor-pressure readings in millimeters of oil have been converted and are presented in the table in millimeters of mercury at 0°C. The percentage relative humidity was calculated by dividing the actual vapor pressure over a solution by that of water at the same temperature and multiplying by 100. In view of the manometer sensitivity and the reproducibility of duplicate determinations, it is believed that the relative humidity values quoted have been measured with an accuracy of ±0.2% R. H. The largest difference in duplicate determinations was 0.3% R. H.

The data are also presented in Figs. 2 to 4 where the relative humidity in per cent is plotted against the temperature of the solution.

### *Stability and Methods of Preparing Solutions*

In conditioning problems where saturated salt solutions are used, two factors are of interest. One is the constancy of the equilibrium relative humidity of the solution and the other is the influence of the method of preparation. For the purpose of ascertaining the effects of these factors, three solutions of each salt were prepared and the equilibrium relative humidities compared by means of an electric hygrometer. The three solutions were a fresh solution (approximately 24 hours

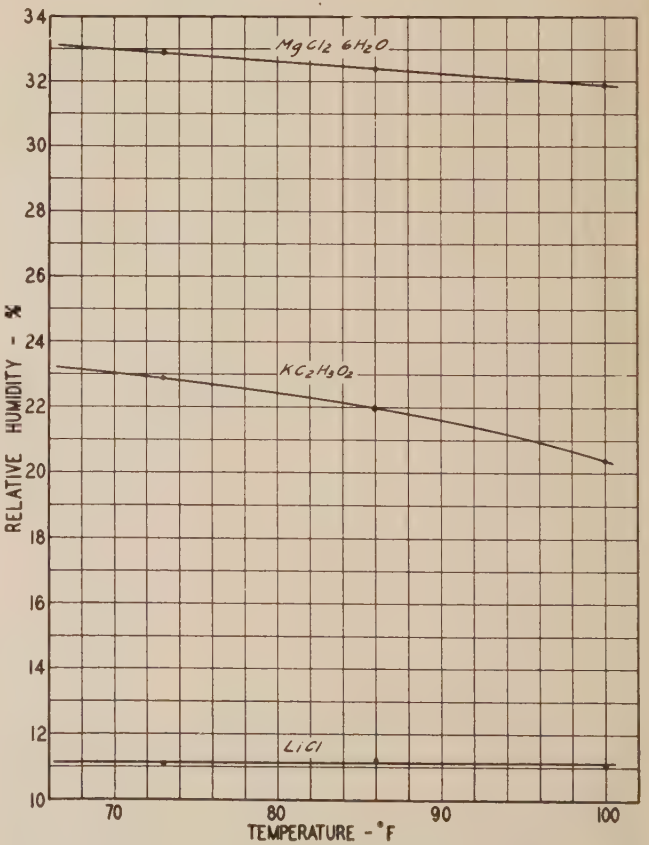



*Fig. 4. Variation of equilibrium relative humidity with temperature over saturated salt solutions*

after preparation), a "heated" solution, and an old solution (approximately 3 months old). The fresh and the old solutions were prepared in the same manner. An excess of the salt (slightly more than was necessary to saturate the solution) was added to distilled water in a bottle. The bottles were shaken occasionally during the first 24 hours of storage at room temperature. The heated solution was prepared by raising the temperature to 100°C. and holding at this temperature until it was evident the salt necessary to saturate the solution at the lower temperature had dissolved. For the salts with a melting point below 100°C., this observation could not be made, and they were therefore held at the elevated temperature for approximately 20 minutes. Upon cooling the solution to room temperature, seed crystals were added to the solution; this was an important step, especially for solutions (such as sodium or potassium acetate) which have a tendency to supersaturate easily. The relative humidity of a supersaturated potassium acetate solution was from 5 to 10% lower than that obtained over a saturated solution. Hence, it is essential in conditioning atmospheres to a constant relative humidity by means of salt solutions always to have excess salt crystals in the solution.

The comparison of the equilibrium relative humidities over the three solutions with the electric hygrometer was carried out in a constant temperature room at 73°F. The solution to be tested was simply transferred to a crystallizing dish and covered with a glass plate to which the electric hygrometer was attached. The edge of the dish was covered with a wax ring in a manner similar to that used in preparing test specimens for water-vapor permeability determinations (*2*) and a moistureproof seal between the wax ring and the plate was obtained with a heavy grease (Celvacene). In testing the old and heated solutions, crystals of the solute were transferred to the crystallizing dish, whereas for the fresh solution, only the supernatant liquid was transferred. The equilibrium hygrometer readings were noted for each solution.

The results indicated that for all but one of the salts, the three solutions produced relative humidities agreeing to 0.3% R. H. Sodium dichromate ($Na_2Cr_2O_7 \cdot 2H_2O$) was the exception. Repeated tests on this solution later revealed that the freshly prepared solution of sodium dichromate was saturated at the end of a week.

During the search for suitable salts, several salts other than those listed in the table were tested and rejected because of undesirable behavior. These salts were: zinc sulphate ($ZnSO_4 \cdot 6H_2O$), potassium fluoride (KF), sodium acid sulphate ($NaHSO_4 \cdot H_2O$), calcium chloride ($CaCl_2$), and a mixture of sodium chloride and potassium chlorate ($NaCl + KClO_3$). An example of misbehavior is calcium chloride which has several transition points at a temperature of approximately 30°C. and, although reproducible relative humidities were obtained above the transition temperature, quite variable results were obtained below that temperature. These results suggest that, when salts having transition points within the temperature range of interest are used, saturated solutions must be prepared and used with care and good judgment if they are to provide stable and reproducible relative humidities.

When conditioning the atmosphere of a small space or cabinet with a saturated salt solution, the enclosure should be essentially moisture tight if it is desired to maintain the relative humidity values, presented in Table I and Figs. 2–4, or the equilibrium relative humidity over any other saturated solution. The time for attainment of equilibrium depends upon the relationship of volume of enclosure to the exposed surface of the solution. This time also depends upon the amount of the material in the enclosure which is either absorbing or giving up moisture. In the case of cabinets, where the moisture seal is questionable, it is always advisable to measure the relative humidity and not depend upon tabulated values. In general, the technique of conditioning any enclosure with a saturated solution is the same as that given in Instrumentation Studies LIV (*3*). Where a space is to be dehumidified, a considerable excess of the salt should be used so that mounds of the salt actually protrude above the liquid; in humidifying a space, the extreme excess of salt is not necessary, although it is important to have some crystals present in the solution.

### LITERATURE CITED


1. Gibson, R. E., and Adams, L. H. Changes of chemical potential in concentrated solutions of certain salts. *J. Am. Chem. Soc.* 55: 2679–2695 (1933).
2. Report No. 30 to the American Paper and Pulp Association. Part III. Techniques for measuring water-vapor permeability—a progress report. Feb. 10, 1943. *Paper Trade J.* 119, no. 2: 23–29 (Jan. 13, 1944).
3. Instrumentation Studies LIV. Penetration of paper by water vapor. VIII. A controlled relative humidity cabinet in which specimens may be weighed without removal from the conditioned atmosphere. *Paper Trade J.* 122, no. 8: 41–46 (Feb. 21, 1946).



This report is one of a series issued as a part of the Instrumentation Program of the American Paper and Pulp Association. The data in this paper were reported to the Association on Feb. 15, 1945 as Report No. 40.


# EMPLOYMENT SERVICE

### Positions Wanted

E76-50. Engineer, 29, family, B.S. degree. Four years' service and sales engineer for instrumentation in pulp and paper mills. Also production control and marine power plant experience. Desires position in either production or mechanical department of northern pulp and paper mill.

E86-50. Chemist. B.S. One year's experience in quality control in specialty mill. Age 25, married, employed. Desires position with responsibility.

E87-50. Graduate chemist. Fifteen years' experience in paper, board, and semichemical pulp. Interested in mill operation or research work. Location not important.

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E89-50. Research director. Paper converting, ordnance, functional, building, industrial anticorrosive, decorative, asphalted, waxed papers, food wraps, synthetic coatings and adhesives. Imaginative know how, initiative. New items, processes, patents pending.

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### Positions Open

P83-50. Paper chemist for large Eastern newspaper publisher. Position in gravure plant in charge of paper quality and rewind room. Some accounting experience desirable.

P84-50. Paper label manufacturer, including gummed and heat sealing labels desires a chemist to have charge of preparation of coating adhesives and assisting customers with their label application problems.

# Holocellulose in Wood

## *Revision of TAPPI Official Standard T 9 m-45*

**(THIS METHOD IS UNDER THE JURISDICTION OF THE CHEMICAL METHODS COMMITTEE)**

Holocellulose is the lignin-free fibrous material comprising all of the hemicellulose and cellulose in wood. It is white, cream, or straw-colored, depending upon the kind of wood. The Cross and Bevan cellulose (T 17 m and T 201 m) does not contain the entire hemicellulose fraction, as some is extracted with the lignin.

### APPARATUS

1. Glass Crucibles with fritted-glass bottom, Pyrex C or M porosity, contained in weighing bottles.
2. Weighting Bottles, of suitable size to contain the glass crucibles.
3. Chlorination Apparatus as shown in Fig. 1.

### REAGENTS

A. Alcohol-Monoethanolamine Solution. A 3.0% solution (by volume) of monoethanolamine in 95% ethyl alcohol.

B. Ethyl Alcohol, 95% by volume.

### TEST SPECIMEN

The test specimen shall consist of at least 6 grams of air-dry extractive-free sawdust, prepared according to TAPPI Standard T 12 m, that has previously been ground to pass a 40-mesh sieve and to be retained on a 60-mesh sieve.

### PROCEDURE

Weigh accurately in duplicate approximately 2 grams of the prepared sawdust in a tared glass crucible contained in a weighing bottle. Determine the moisture content on the remainder of the test specimen.

Using slight suction, chlorinate the moist sample by passing chlorine gas through a funnel inverted over the crucible which is in position on a suction flask. Keep the crucible and contents cool with ice water. After chlorinating for 3 minutes, remove the inverted funnel, stir the wood thoroughly, and rechlorinate for 2 minutes.

Add alcohol to dissolve excess chlorine and HCl and after 1 minute remove by suction. Release the vacuum, drain off the ice water, add sufficient hot alcohol-monoethanolamine (75°C. or higher) to cover the wood completely, and stir thoroughly. Let the solution stand 2 minutes, then remove by suction. Repeat the solvent treatment. Remove any remaining solvent by washing twice with 95% alcohol, then twice with cold water. Remove the wash liquids by suction. The above procedure is not sufficient to remove all the lignin, so repeat the treatment with chlorine and subsequent extraction and washing as outlined above until the color of the residue is white or fails to change with additional chlorination. The second and following treatments with chlorine (after washing the specimen in the crucible with distilled water) should not require more than 2 or 3 minutes. Prolonged action of chlorine gas, together with the HCl formed in the secondary reactions, hydrolyzes the holocellulose and gives low yields. After all the lignin has been removed, wash the fibers twice with alcohol to remove the alcohol-ethanolamine,

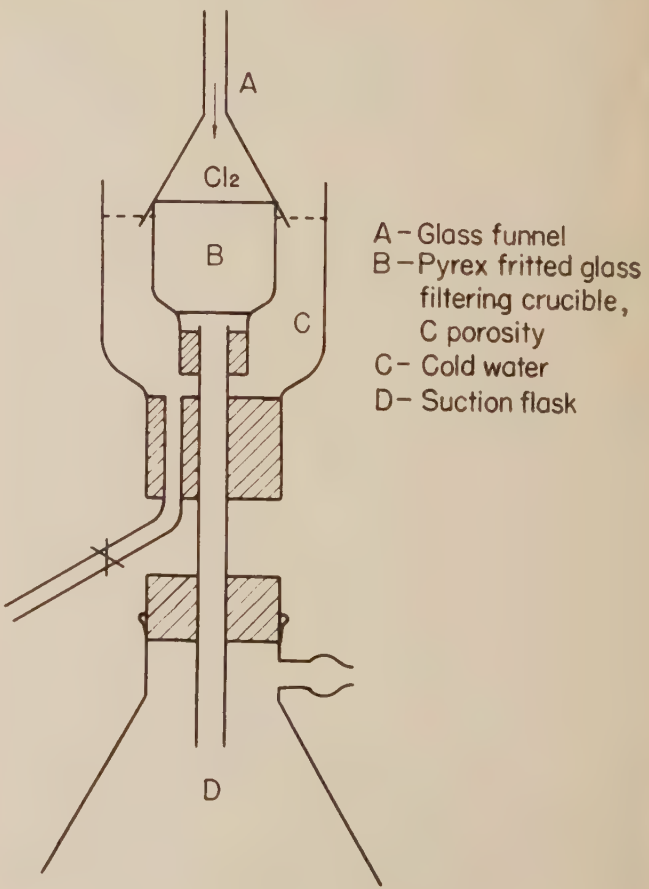


*Fig. 1. Chlorinator for holocellulose*

twice with cold water, and again with alcohol until the residue is neutral to litmus. Finally wash thoroughly with ether to remove all the alcohol and to facilitate drying.

Air-dry the holocellulose to remove excess ether and then dry for $2^1/_2$ hours at 100 to 105°C. in an oven. (If subsequent analyses or tests are to be made on the holocellulose, it should be dried at 60°C. *in vacuo*.) Finally place the tared crucible in the original stoppered weighing bottle, cool in a desiccator over conc. $H_2SO_4$ and weigh to obtain the holocellulose.

### REPORT

The result shall be reported as percentage by weight of holocellulose in the moisture-free, unextracted wood to one decimal place.

### ADDITIONAL INFORMATION

1. A fraction comparable to Cross and Bevan cellulose can be determined from the holocellulose as follows:

Place the crucible and contents from the holocellulose determination (dried *in vacuo* at 60°C.) in a 600-ml. beaker and add 200 ml. of boiling 1.3% $H_2SO_4$. Place the beaker and contents in a boiling water bath having a liquid level coinciding with that of the solution in the beaker and continue hydrolysis for 2 hours. Maintain the original levels of the acid solution and the water bath by the addition of water.

Remove the crucible from the acid and wash back into the beaker with distilled water any of the suspension remaining on its outer surface. Filter the acid mixture through the same crucible and wash the hydrolyzed holocellulose residue with hot water under suction until neutral to litmus, then with 20 ml. of alchol and finally with 20 ml. of ether. Air-dry the residue to remove the excess ether and then dry to constant weight in an oven at 100 to 105°C. Calculate the weight as the percentage of Cross and Bevan cellulose on the basis of the moisture-free specimen.

2. The lignin content, determined by the sulphuric acid method, plus the holocellulose content of the moisture-free wood should theoretically equal 100%.

### REFERENCES

Van Beckum, W. G., and Ritter, G. J., *Paper Trade J.* 105, no. 18: 127–130 (Oct. 28, 1937); *Tech. Assoc. Papers* 21: 431–434 (June, 1938).

Kurth, E. F., *Paper Trade J.* 126, no. 6: 56–58 (Feb. 5, 1948); *Tech. Assoc. Papers* 31: 614–615 (June, 1948).

This method has been approved as a revised standard by the Chemical Methods Committee. Criticisms are earnestly requested and shoud be sent to R. G. Macdonald, Secretary, Technical Association of the Pulp and Paper Industry. 122 E. 42nd St., New York 17, N. Y.

# LETTERS TO THE EDITOR

## *Fire Resistance of Wallboard*

To the Editor, *Tappi:*

Several men in the insulation board industry have voiced to me their disapproval of Method RC-51, "Fire Resistance of Wallboard," which has been apparently circulated to the TAPPI membership. The test was probably developed for use on gypsum board and similar products, but the term "wallboard" is often applied to insulating board, and such a severe exposure as described would make a sad mess of our type of product, even though it is classified as "Flame Resistant Finished Surface" under Commercial Standard CS-42-43.

I am asking Mr. Frederick through his copy of this letter to let a flame test method receive the early attention of his subcommittee on finished product test methods.

I feel certain that I express the opinion of the entire insulating board industry in voicing strenuous objection to the adoption of Method RC-51 for insulating wallboard.

JOHN F. CAMPBELL, *Chairman*
Structural Fibrous Materials Committee

# RECENT BOOKS

**Engineering Papers of the Hydraulic Institute, Vol. III.** Hydraulic Institute, 90 West St., New York 6, N. Y. Paperboard, $8^1/_2 \times 11$, 61 pages. $2.00.

This volume contains award winning papers offered in engineering contests sponsored by the Hydraulic Institute for the employees of its members (pump manufacturers), to stimulate their interest in the many phases of the pump industry.

The sections covered include "Cavitation of Centrifugal Pumps," by A. T. Stepanoff, Ingersoll-Rand Co., "The Centrifugal Pump in the Process Industries," by A. T. Nielsen, Worthington Pump & Machy Co. "The Operation of Centrifugal Boiler Feed Pumps," by Hans Gartman, De Laval Steam Turbine Co., and "Submergence for Centrifugal Condensate Pumps," by Hollis T. Waldo, Warren Steam Pump Co.

**The Fundamentals of Detergency.** By William W. Niven, Jr., Research Chemist, Midwest Research Institute, Kansas City, Mo. 1950. Cloth 6 × 9, 256 pages. Illustrated. Reinhold Publishing Corp., $5.50.

This is a book for those who desire a basic knowledge of the factors involving detergency and who wish to understand the chemical formulation of modern detergents. Its principles can be applied to all fields in which surface tension and related phenomena play a part. It bridges the gap between general and specialized information on detergency. Included in the section on practical considerations are such subjects as separation of soil from fabric, dispersion of soil in the detergent solution, stabilization of dispersed soil, comprehensive summarization of detergent action and present knowledge of detergency vs. present washroom practice.

**Quantitative Organic Analysis via Functional Groups.** By Sidney Siggia, Research Analyst, General Aniline & Film Corp. John Wiley & Sons, Inc. New York, 1949. Cloth $5^1/_2 \times 8^1/_2$, 152 pages, Illustrated. $3.00.

With the growing emphasis on organic chemistry this book makes a real contribution to time saving for the analyst. When seeking a method of analysis for a certain type of compound much time is saved since this text eliminates the need for searching through the literature and for weeding out and testing procedures that show promise. The author had to follow this procedure and realizing the tedium involved has put his findings in this book. Examples of groups covered are hydroxyl, carbonyl, carboxylic acid, acetal, amino, mercapto, dialkyl, sulphonic, vinyl, etc. The procedures are so described that they may be applied directly from this book.

**Elements of Engineering Reports.** By Dale S. Davis, Professor of Chemical Engineering, Virginia Polytechnic Institute. Paperbound $5^1/_2 \times 8^1/_2$, 176 pages. Lithoprinted from the Author's typescript by Edward Brothers, Inc., Ann Arbor, Mich. Avai-

able, Bookstore, Virginia Polytechnic Institute, Blacksburg, Va. $1.65.

Representing the latest distillation from the literature and editorial experience on proper report writing technique, the book begins with the cover of a report and proceeds to its appendix, giving clear, complete, concise, and helpful information to its readers. One chapter dealing with illustrations and tables shows the best methods for presenting data and results in tabular and graphical form.

A chapter of over forty pages is devoted to common faults and errors encountered in technical reports along with the recommended practices for their correction. As a result of the author's long association with the pulp and paper industry, the illustrations in this as well as in other sections of the book, are drawn from reports dealing with this industry.

Another chapter, containing 18 illustrative figures, is devoted to graphical representation of engineering equations. The three main methods of presentation: a curve or ordinary coordinate paper, a straight line on specially ruled coordinate paper, and a nomograph are given along with the advantages and limitations of each month. Also included are comprehensive sections on spelling, nomenclature, precision of measurements, and editorial practice.

A chapter on measurement precision presents a review of the rules governing computations and shows, by means of detailed examples, how to make simple but adequate precision studies.

Illustrative reports are presented, interspersed with comments and suggestions; in others editorial changes have been marked in detail. Several rough drafts are left as exercises for the reader.

The appendix contains a great deal of helpful information including a convenient form for a development work report as devised by Professor F. C. Vilbrandt, of the Virginia Polytechnic Institute.

Humorous illustrations of often-met errors are extensively used throughout. The work should prove useful as a text for men preparing for industrial work and as a guide for those already engaged in providing the world with its luxuries and essentials.

Men who find themselves called upon to put their findings and ideas in concrete form should realize a large rate of return from this volume. (R. C. Scott, Jr.)

**Paper Cutting: Machines and Techniques.** By George J. Mills, Carnegie Institute of Technology. Paperbound $8^3/_8 \times 11$, 26 pages. Illustrated. Available from G. J. Mills, Box 265m, Carnegie Institute of Technology, Pittsburgh 13, Pa. $1.25.

This is the first extensive writing on this subject since the Typothetae book in 1918 and has received enthusiastic response from printers and printing teachers in the U. S. and Canada. It is of value to anyone who cuts or handles paper, particularly to the novice. It covers basic cutting principles, hand lever and power cutters, points to consider in buying a paper cutter, care and change of knives, paper storage and transport, how to figure spoilage, and time-saving methods of trimming.

**Outlines of Biochemistry.** 3rd Ed. Edited by Ross Aiken Gortner, Jr., Wesleyan University and Willis Alway Gortner, Pineapple Research Institute. John Wiley & Sons, Inc. New York, 1949, Cloth $6 \times 9^1/_2$, 1078 pages. Illustrated. $17.50.

This book carries forward the work of Ross Aiken Gortner, late Chief of the Division of Agricultural Biochemistry, University of Minnesota. Ten major contributors, nearly all former students of Dr. Gortner, participated in the preparation of this edition. One of these is Samuel I. Aronovsky, Chairman, TAPPI Fibrous Agricultural Residues Committee. The present revision is the first in eleven years. With so much new information available it was difficult to keep the size of the edition within reasonable limits.

As indicated by its title the book is a complete discussion of the fundamental organic and physico-chemical reactions of plant and animal organisms and the colloidal system in which they take place. The major subjects covered are colloids, proteins, carbohydrates and related substances, the lipids and essential oils, plant pigments, and biochemical regulators such as vitamins, hormones, and enzymes.

**Quality Control and Statistical Methods.** By Edward M. Schrock, Refrigeration Quality Control Div., General Electric Co., Erie, Pa. Reinhold Publishing Corp., New York. 1950. Cloth $6 \times 9$, 213 pages. Illustrated. $5.00.

This book is intended for those who are relatively new to the field and wish to improve their effectiveness in appraising and controlling the quality of products or the economy of methods to increase production.

Many who have attended TAPPI meeting sessions sponsored by its Statistics Committee have expressed some bewilderment regarding the subject and although conceding that the techniques may have an application in the manufacture of machine parts it is difficult to know how they can be applied to paper manufacture. In his introduction he anticipates this situation by answering three questions. (1) Why are statistical methods of quality control important? (2) How can I sell the desirability of modern statistical quality control to management? and (3) Where does quality control fit into my organization?

Among the subjects covered are case histories showing what statistical methods have to offer, summarization of data, the quality control chart for variables and its interpretation, acceptance sampling, and suggestions for further reading.

**Organic Chemistry.** By Paul Karrer, Professor, University of Zurich. Original translation by A. J. Mee, 4th English Edition. Elsevier, Publishing Co., Inc., New York 1950. Cloth $6^1/_2 \times 10$, 973 pages. $8.50.

This book which is well known to students of organic chemistry has been revised and enlarged in accordance with the 11th German edition. It has four major parts: I. Aliphatic Compounds, II. Carbocyclic Compounds, III. Heterocyclic Compounds, and IV. Organic Compounds with Heavy Hydrogen and Heavy Oxygen. It is remarkably well illustrated with structural equations.

**Fundamentals of Synthetic Polymer Technology.** By R. Houwink, Lecturer in the University of Felft, Netherlands. Elsevier Publishing Co. New York. 1949. Cloth, $6^1/_2 \times 9^1/_2$, 258 pages. $3.75.

This is a completely revised edition of Technology of Synthetic Polymers (1947) by the same author. Although many books have been published on this subject, this book is essentially different in that it touches the fundamental background of the chemical and physical factors in the preparation and use of synthetic polymers. A feature of the book is a review of the views and methods prevailing in North America. Great Britain, and Europe. Among the subjects covered are the chemistry of the polymers, bonds inside and outside of molecules, physics and colloid chemistry of polymers, testing of properties, processing of polymers, polymers based on cellulose, proteins, rubbers, etc., silicones and economic aspects.

**The Analytical Chemistry of Industrial Poisons, Hazards, and Solvents.** 2nd Ed. By Morris B. Jacobs, Adjunct Professor of Chemical Engineering, Polytechnic Institute of Brooklyn. Interscience Publishers, Inc., New York. 1949. Cloth, $6 \times 9^1/_2$, 788 pages. $12.

This is Volume I in a series of monographs on Analytical Chemistry and Its Applications, edited by B. L. Clark and I. M. Kolthoff. The present volume brings up to date the material published eight years ago in the first edition. Among the subjects covered are sampling, measurement of gas volume, absorbents, estimation of dust, silica, lead, mercury, arsenic, compounds of sulphur, the halogens, paraffins, acids, phenolics, etc.

Copies of books reviewed in this section may be obtained from TAPPI, 122 East 42nd Street, New York 17, N. Y.

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## Calendar of TAPPI Meetings

### NATIONAL

Fifth Engineering Conference of the Pulp and Paper Industry. Netherland Plaza Hotel, Cincinnati, Ohio, October 2–5, 1950.

- General Chairman—G. H. Pringle, Mead Corp., Chillicothe, Ohio.
- Steam and Power Committee—C. J. Sibler, West Virginia Pulp and Paper Co., New York, N. Y., Chairman.
- Materials Handling Committee—A. P. Schnyder, Ebasco Services, Inc., New York, N. Y., Chairman.
- Drying and Ventilating Committee—M. L. Barker, Beckett Paper Co., Hamilton, Ohio, Chairman.
- Engineering Research and Machine Design Committee—P. H. Goldsmith, Pusey & Jones Corp., Wilmington, Del., Chairman.
- Mill Design and Engineering Aspects Committee—Alvin H. Johnson, New York, N. Y., Chairman.
- Hydraulics Committee—K. J. Mackenzie, Eastman Kodak Co., Rochester, N. Y., Chairman.
- Mill Maintenance and Materials Committee—H. F. Parker, New York and Pennsylvania Co., Lock Haven, Pa., Chairman.
- Electrical Engineering Committee—A. S. Goodrich, Hammermill Paper Co., Erie, Pa., Chairman.
- Chemical Engineering Committee—J. R. Lientz, Union Bag & Paper Corp., Savannah, Ga., Chairman.
- Data Sheets Committee—H. J. Perry, Lockwood Trade Journal Co., New York, N. Y., Chairman.

Plastics Conference. New York State College of Forestry, Syracuse, N. Y. October 19–20, 1950.

Alkaline Pulping Conference. George Washington Hotel, Jacksonville, Fla., October 25–27, 1950.

Fibrous Agricultural Residues Conference. Northern Regional Research Laboratory, Peoria, Ill., November 12–13, 1950.

### LOCAL SECTIONS

OHIO SECTION:
October 10, 1950, Manchester Hotel, Middletown.

NEW ENGLAND SECTION:
September 29, 1950, Red Lion Inn, Stockbridge, Mass.

MAINE-NEW HAMPSHIRE SECTION
October 13–14, 1950, Colby College, Waterville, Me. Room reservations at Elmwood Hotel.

DELAWARE VALLEY SECTION:
September 28, 1950, Visit to Triangle Publishers, Inc. Printing Plant. Dinner meeting at Broadwood Hotel, Philadelphia, Pa.

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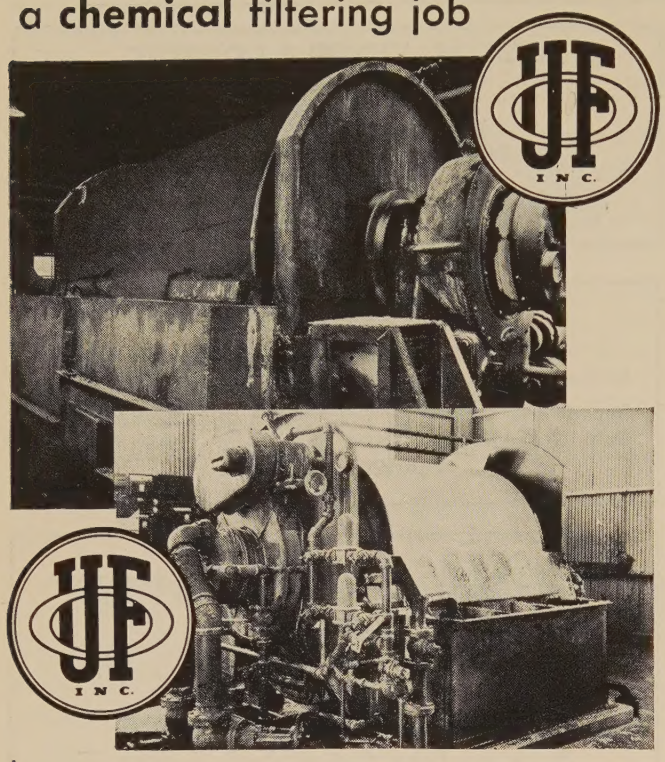

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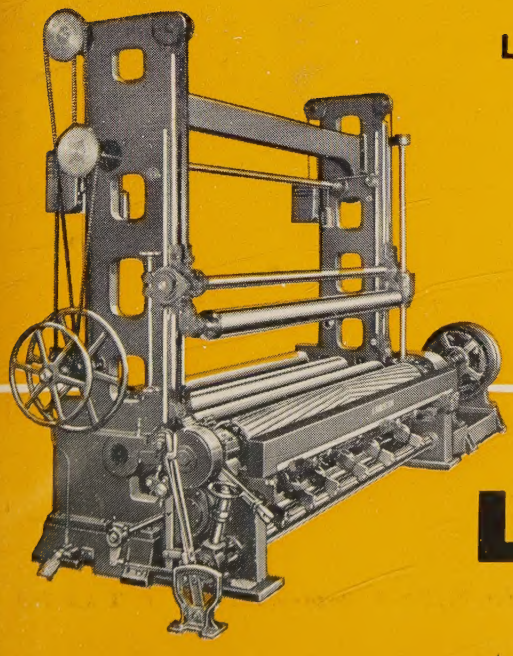

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